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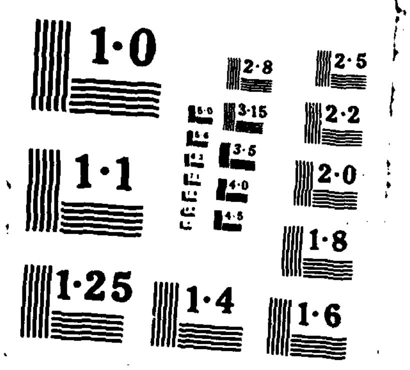
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VALIDATION OF THE TACTICAL AIR FORCE'S DECISION MAKING PROCESS TO PRIORITIZE MODIFICATIONS USING THE ANALYTIC HIERARCHY PROCESS

THESIS

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Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

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Preface

The purpose of this study was to validate the decision making process TAF uses to prioritize their potential R&M improvement modifications and to suggest other possible approaches to solve their prioritization problem.

In performing the research and writing this thesis I have received a great deal of help from others. I am deeply indebted to my faculty advisor, Capt Joseph Tatman, for his enthusiasm and his words of encouragement. I would also like to thank my thesis reader, Lt Col Thomas Schuppe, for his thoughtful insights.

Katherine H. Darko

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Abstract

The purpose of this research was to validate TAF's decision making process that generates a prioritized list of R&M modifications and to suggest other possible approaches to solve the problem.

The first part of the research, the validation, was done in three sections. The first section demonstrated that TAF does not completely satisfy the requirements to meet a specific set of decision criteria, but the shortcomings may be easily corrected. Also explained was the applicability of using the AHP to solve TAF's problem. The second section scrutinized TAF's use of the AHP to determine problem areas. The tree structure and the data were discussed and possible fixes were introduced. The third section highlighted three shortcomings contained within the AHP. The topics of dependency between the mods, uncertainty in the data, and the scale used to make the comparisons were discussed in detail. Ideas on approaches to avoid these problems were presented.

The second part of the thesis proposed the alternative methods of decision analysis and PROMETHEE to solve TAF's prioritization problem.

VALIDATION OF THE TACTICAL AIR FORCE'S DECISION MAKING PROCESS TO PRIORITIZE MODIFICATIONS USING THE ANALYTIC HIERARCHY PROCESS

I. Introduction

Annually, the Tactical Air Force (TAF) needs to develop a prioritized list of its reliability and maintainability modifications (mods) to aid the decision makers who allocate funds to the modification programs. To develop this list, TAF uses a decision making process called the analytic hierarchy process (AHP). Since the prioritized list is so important, TAF is interested in validating their use of the AHP. The validation will need to consider three areas: (1) how well TAF satisfies the criteria necessary to make a good decision, (2) if TAF is correctly using the AHP, and (3) shortcomings that exist within the AHP that may pose problems for TAF.

Specific Problem Statement

TAF has not yet validated the process with which their prioritized list of mods is developed. The purpose of this research is to validate TAF's decision making process that generates a prioritized list of reliability and maintainability modifications and to suggest other possible approaches to solve the prioritization problem. The

validation will be done in three parts. The first part will consider the criteria one should follow when making a decision and then demonstrate how well TAF succeeds in fulfilling these criteria. Also discussed are the reasons for using the AHP approach to solve a problem. This is followed by an analysis of the appropriateness of TAF solving their specific problem using the AHP. Second, TAF's use of the AHP will be scrutinized to determine areas where they may not be performing optimally. Third, some shortcomings that are contained within the AHP will be presented since they may pose hidden problems to TAF. The second part of the research will propose alternative methods to solve TAF's prioritization problem. These methods will improve on or eliminate some of the identified problems with TAF's AHP approach.

Motivation for Managers

This paper may assist decision makers, who are faced with a complex decision to make, in three areas. First, ideas on some criteria that should be considered and met when trying to make a decision involving the ranking of various alternatives will be presented. The criteria will help him to determine if the decision process used was satisfactory by supplying him with a set of standards to compare the process against. Second, the AHP will be explained in enough detail to enable the decision maker to decide if this technique would apply to solving his

particular decision. If the AHP seems an appropriate method, the decision maker will be introduced to ideas on how best to accomplish the technique, as well as ideas on some problems he may encounter. Third, this paper will present alternative methods to solve complex decision problems that may better apply to the decision maker's specific problem.

Subobjectives of the Research

1. Validation of the decision process

   A. Identify the criteria that need to be considered when making a decision such as TAF's decision

   B. Analyze TAF's fulfillment of these decision criteria

2. Validation of the applicability of the AHP

   A. Identify reasons to use the AHP when making a decision

   B. Analyze the existence of these reasons in TAF's decision problem

3. Validation of the application of the AHP

   A. Identify several major areas where TAF may encounter problems in their use of the AHP

   B. Analyze TAF's use of the AHP considering these problem areas

   C. Suggest ways TAF may overcome these problems (restructure their existing tree and develop a new R&M 2000 tree)

4. New methods to do the prioritization of the mods

A. Determine what other methods exist for prioritizing TAF's alternatives

B. Determine the relevancy of these methods

C. Determine if these methods would improve the prioritized list obtained through the AHP

II. Background

This chapter is divided into two sections. The first section provides the background necessary to understand why the Tactical Air Force needs a prioritized list of mods. The second section explains how the Tactical Air Force develops the list using the analytic hierarchy process.

What TAF Needs and Why

The United States Air Force meets a significant portion of its mission requirements through the deployment of new weapon systems and the modification of existing weapon systems. "Modifications (mods) add new capabilities, correct deficiencies, improve reliability and maintainability, and extend the life of existing weapon systems (6:1)". This paper will focus on Class IVB mods which are those that "change a configuration item for reasons of material deficiencies or to improve reliability and maintainability (R&M) (6:1)". The acquisition of Class IV mods is currently being funded at a level of over one billion dollars a year (6:1). Due to limited funds, the Class IV mods must be prioritized on an Air Force-wide basis. This prioritization is accomplished by Headquarters Air Force Logistics Command using the H040 algorithm. Using the data supplied by the system program managers working in conjunction with the operating commands, this algorithm produces an integrated Air Force Logistics Command Class IV

mod ranking. This listing is then submitted to HQ USAF/LE-RD at the Pentagon in support of the Program Objective Memorandum and the Budget Estimate Submission (6:2).

The Tactical Air Force, consisting of the Tactical Air Command, United States Air Forces in Europe, Pacific Air Forces, Alaskan Air Command, the National Guard Bureau, and the Air Force reserves, is one of the operating commands who submit a prioritized list of their mods to the Air Force Logistics Command. Developing this prioritized list is a difficult task. The Tactical Air Force could not use the HO40 algorithm to do the prioritization since the HO40 algorithm was developed in 1979 and is primarily based on the mod status (i.e. its feasibility or budget execution (6:5)) rather than the system program managers' priority, mission need, and reliability and maintainability improvement (6:iii).

The Air Force renewed its commitment to reliability and maintainability (R&M) in 1985 by "placing R&M coequal with cost, schedule, and performance for research, development, acquisition, and modification of future and existing weapon systems (24:I-2)". This renewed commitment was embodied in the United States Air Force R&M 2000 Plan (24:v). Since the HO40 algorithm was developed six years before the R&M 2000 push it does not consider the goals laid out by the R&M 2000 plan. However, the Tactical Air Force is required to follow the plan.

Thus, the Tactical Air Force needed to find a way to prioritize its Class IVB mods that took cost, mission, and improved R&M into consideration. Since it is difficult to compare such diverse characteristics of the mods, the Tactical Air Force realized they needed a process that could handle the diversity. In a similar situation, the Tactical Air Command had used the Planning and Programming Priority Project (P4) model to rank program objective memoranda. In this case the decision makers had to rank very diverse projects such as installing a new F-15 wing or a new gymnasium (22). The P4 model was chosen in this case because it used the analytic hierarchy process which is "suitable for solving complicated and elusive decision problems (27:96)". Since the P4 model yielded such outstanding results in this application to the program objective memoranda, the Tactical Air Force decided to use it to rank its modifications (22).

The prioritized list that is derived from the output from the P4 model is sent to AFLC LOC/CC and AFLC/CC who are in charge of the HO40 model. The list is also forwarded directly to USAF/ LE-RD so that the people there will know the Tactical Air Force's priorities on the mods before the mods are put through the HO40 algorithm (5). The list is also published annually in the Tactical Forces Multicommand R&M 2000 Plan, Volume II (24:vi). Due to the high visibility of the list, the Tactical Air Force needs a validation and possible improvement of the process they use

to do the prioritization of the mods. In other words, they need their use of the analytic hierarchy process validated.

TAF's Process to Develop the List

Remember that the model used by the Tactical Air Force to develop the prioritized list of their mods is based on the analytic hierarchy process. The theory of the analytic hierarchy process had its beginnings in 1971 (19:iv). Saaty believed then that a process could be developed to aid decision makers in reducing "formidably intricate systems to a sequence of pairwise comparisons of properly identified components (19:4)". For example, Saaty considers the familiar complex problem of comparing apples to oranges.

> An apple and an orange may have many characteristics in common: size, shape, taste, aroma, color, seediness, juiciness, and so on. In addition, the strength of our preference for these characteristics may vary. We may be indifferent to the size and color but may have a strong preference for taste which again may vary with the time of day [19:xi].

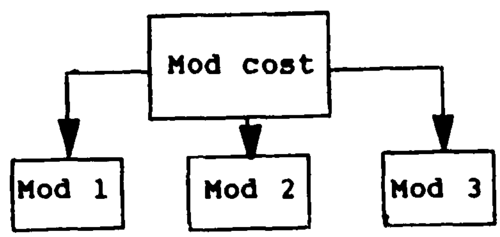
With the goal of being able to deal with problems similar to this one, Saaty developed the analytic hierarchy process.

The analytic hierarchy process solves decision problems in four steps. First, a decision hierarchy that structures the problem is set up by the decision analyst (23:98). This structure places the decision objective at the top, attributes that contribute to the quality of the decision in the middle, these will be called decision elements, and decision alternatives at the bottom (27:96-97). For example, in the apple and orange comparison, the top level

will be the objective of choosing a piece of fruit to eat. The characteristics of the fruit would occupy the middle levels, and the decision alternatives of types of fruit to eat would occupy the lowest level. The second step in the analytic hierarchy process involves the collection of data by "pairwise comparison of decision elements (27:96)". In our example, data could be collected by comparing the taste, color, and juiciness of apples to oranges. The third step in the process is a solution step that establishes priorities among elements of the hierarchy (23:98). This step would yield relative weights for the importance of taste, color, and juiciness in the apple and orange comparison. The fourth step aggregates the relative weights from the third step and produces a "vector of composite weights which serve as ratings of decision alternatives... in achieving the most general objective of the problem (27:99)". In other words, it ranks the decision alternatives from the best to the worst. With this introduction to the analytic hierarchy process, the Tactical Air Force's application of its four steps will now be discussed.

To accomplish the first step of the analytic hierarchy process the Tactical Air Force had to do two things. First, it had to structure its problem by setting up the decision hierarchy and second, it had to identify all the potential mods. The decision hierarchy was set up by identifying the decision objective as getting the most R&M

improvement benefit while minimizing the cost. The decision elements were identified as reliability improvement, maintainability improvement, inventory size, mod cost, and remaining life cycle (see Figure 1). The decision alternatives (although not shown in the figure) are the proposed mods. The entire set of proposed mods are located directly beneath each of the five final decision elements. For example, if there are three proposed mods then the mod cost node would look like the following.



To identify all the potential mods, the Tactical Air Force needs to contact the using commands of the aircraft, specifically the system program managers for the various Tactical Air Force aircraft (5). The system program managers at the Air Force Logistics Centers receive all the proposed mods for their aircraft by two means. First, the field units will identify mods and submit them to their Tactical Air Command functional managers who forward the mods to the system program manager. Second, the staff agencies of the major commands will see pressure points and contact the system program manager directly with potential mods (5). The Tactical Air Force collects these mods every

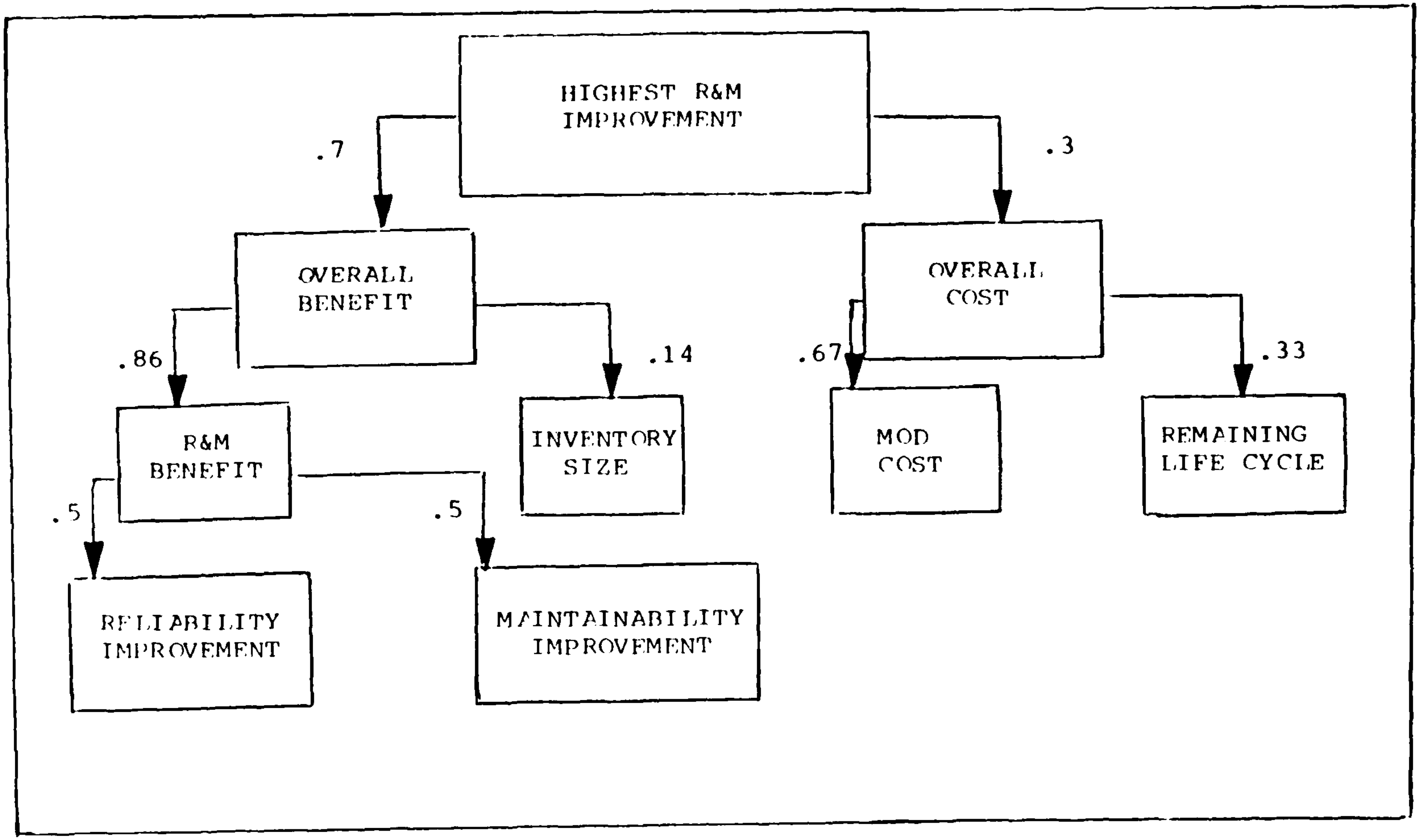


Figure 1. The Current TAF Tree (TAFTREE)

November and pulls out the most important ones. These mods are the ones that ultimately appear as the decision alternatives at the bottom level of the decision hierarchy.

The second step of the analytic hierarchy process requires first that relevant data be collected on the various decision alternatives and second that a pairwise comparison of the decision elements be performed. The data that the Tactical Air Force uses is collected from several sources. First, data on the reliability and maintainability improvements come from the Maintenance and Operational Data Access System (MODAS), which is a "central, on-line, interactive data storage and processing of maintenance and operational data on selected USAF weapon systems (12:2-1)", under the Air Force Logistics Command. The data for the inventory size and the mod cost come from the Air Logistics Centers of the specific aircraft that the mod will be performed on. Data on the remaining life cycle of the aircraft on which the mod will be done is a figure drawn from knowledge of the aircraft and an educated guess of the year its replacement will occur. All of the data collected is entered on a worksheet; one worksheet for each proposed mod. These worksheets are filled out by the program managers residing at the Air Logistics Centers where the various aircraft systems are located (5).

The Tactical Air Force takes this data and does a pairwise comparison of each decision element for the proposed mods, which are the decision alternatives. To

accomplish this step, a panel of about ten people with experience in the various Tactical Air Force aircraft are chosen from the Headquarters Tactical Air Command aircraft functional managers, product improvement personnel from the Tactical Air Command, and Headquarters Tactical Air Command SMO-R&M personnel (5). The panel meets for approximately two full days and makes the comparisons.

For example, assume there were three mods; A, B, and C (decision alternatives), and the decision elements the Tactical Air Force has identified in their hierarchy tree. The panel would compare mod A to mod B in terms of reliability improvement and determine which one was better and by how much. In this case, mod A is strongly preferred to mod B in reliability improvement (see Figure 2). Then mod A would again be compared to mod B in terms of maintainability improvement. These comparisons would continue for all five decision elements. Then mod A would be compared to mod C, and then mod B to mod C. The new data generated by these pairwise comparisons are now available for use in the fourth step of the analytic hierarchy process.

The third step of the analytic hierarchy process establishes priorities among the decision elements of the hierarchy. On the Tactical Air Force tree, for example, the relative importance of the overall benefit to the overall cost has been set as .7 to .3. In other words, benefit contributes 70% to the goal of highest R&M benefit for the

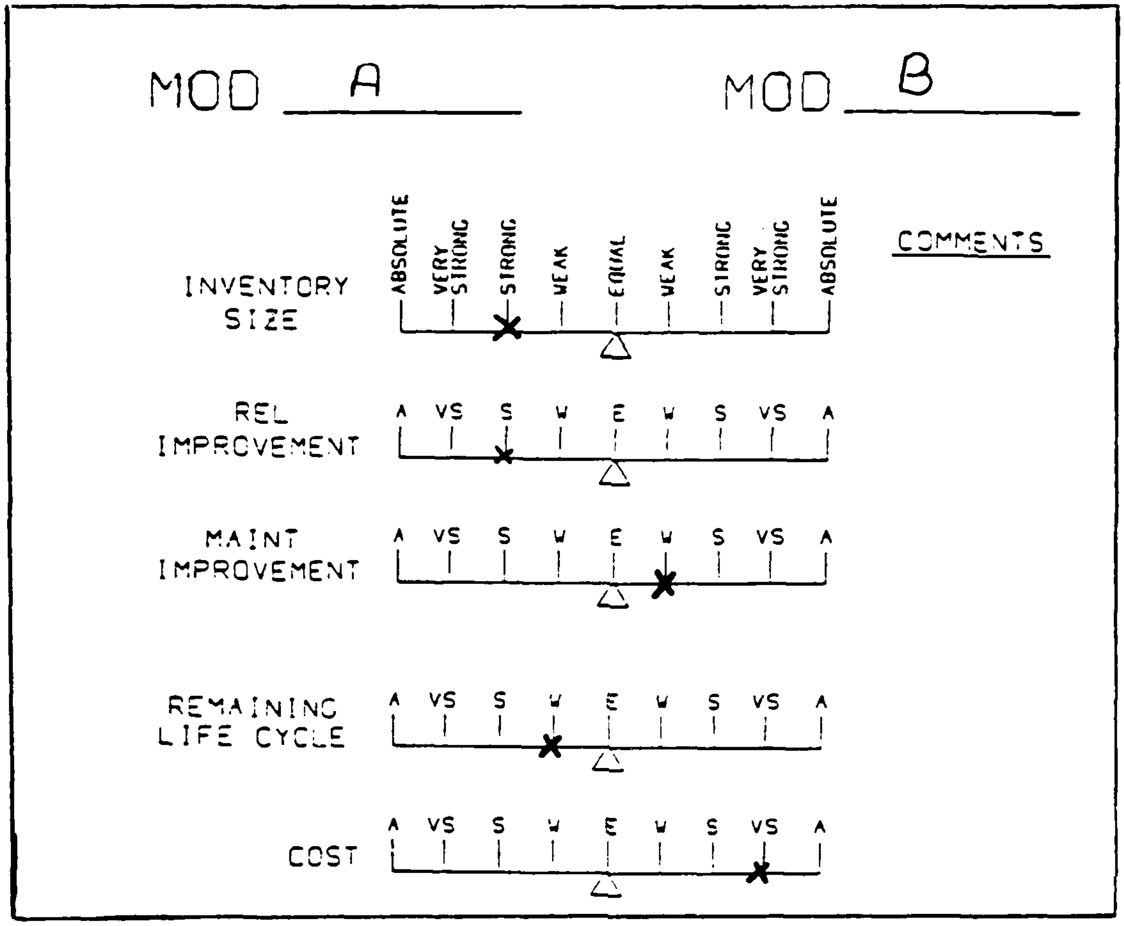


Figure 2. Teeter-totter

minimum cost while cost only contributes 30% to this goal. The Tactical Air Force established these weights with knowledge of what their organization ultimately felt was important.

The fourth step of the analytic hierarchy process aggregates all the weights to yield a value for each mod. For example, if mod A had a weight of .2 for reliability improvement, .2 for maintainability improvement, .6 for inventory size, .6 for mod cost, and .1 for remaining life

cycle, it would get a value of:

$$(.2)(.5)(.86)(.7) + (.2)(.5)(.86)(.7) + (.6)(.14)(.7) + (.6)(.67)(.3) + (.1)(.33)(.3) = .3097$$

by summing up all the values at each end node multiplied up through the tree. The way the Tactical Air Force accomplishes this step is by using the Planning and Programming Priority Project (P4) model. The hierarchy tree and the data from the second step of pairwise comparisons is input into P4 and the model assigns the mod values at each decision element, for example it would provide a value of .2 for mod A at the reliability improvement node. P4 then synthesizes all the values for all the mods up the branches on the decision tree to yield the mods' overall values which indicate how much those mods contribute to the overall goal.

From these final values for each mod, the Tactical Air Force is able to rank the mods starting from the mod that contributes the most to the overall goal down to the one that contributes the least. This is the list that they then forward to the Air Force Logistics Command and to the Air Staff.

III. Methodology and the TAF Decision Making Process

Steps Done in the Validation

This and the next two chapters investigate the decision process TAF uses to arrive at a prioritized list of R&M mods. This chapter looks at the general decision and discusses several problems TAF might be facing. Then, given that the decision is structured and uses the AHP to solve the problem, Chapter 4 presents and critiques TAF's use of the AHP. Last, given that the the AHP is properly applied, hidden problems within the process itself are explored in Chapter 5.

This chapter will begin by briefly presenting the steps taken to acquire the information, data, and understanding required to satisfy TAF's need for a validation of their decision process. This is followed by a very general view of what steps need to be taken for any decision to ensure that the decision made is a good one. A discussion on how well TAF accomplishes these steps will follow. Then a section on the specific criteria TAF needs to meet for their decision to be satisfactory is presented. The last section of the chapter discusses the applicability of the AHP to TAF's decision problem.

Steps for Information Gathering

The steps taken to gather the information necessary to accurately validate TAF's decision making process for the

prioritization of mods can be divided into the four main categories of discussing ideas with the analyst who requested the validation, discussing topics with experts in various fields related to the research, conducting an extensive literature review on many related topics, and learning how to use a software package called Expert Choice (7). Each category will now be discussed in detail.

A trip was taken to Langley AFB, Virginia in June of 1987 when the research was just beginning. Two days were spent discussing the process TAF uses in prioritizing its mods and their need for a validation of their process. Captain Wallace Collins of TAC SMO-R&M was the analyst contacted. Appropriate reports, computer runs, and correspondence were obtained for background information. Questions that were prepared prior to the meeting were answered in sufficient detail to permit progress in the research effort. A visit was made to Lieutenant Richard Schooff of TAC/XP-JSG, also located at Langley AFB. From him many insights into the workings of the model used by TAF in solving their problem were gained.

Following the trip to Langley, a need for detailed information about data, R&M 2000, and various other topics was needed. At this point experts in the various fields were contacted. Some names were provided by Captain Collins and some by the thesis committee. This acquisition of the necessary information was an iterative process in certain situations due to the complexity of the topics.

The literature review was done from the beginning to the end of the thesis. As more areas were uncovered and more questions arose, the need for articles by experts in the field were needed. The literature search was focused primarily on the AHP, its applications, and its shortcomings. Many articles were also found dealing with the subject of decision making, specifically multiple-criteria decision making.

The software package Expert Choice which is used with the micro-computer was invaluable. It was used to solve sample decision problems using the AHP. This package was used for all the examples presented in this paper. It allowed for quick changes in the decision tree structure and weights so that it was usually an easy task to find a case to prove a point trying to be made.

General Steps

In any decision there are certain specific steps that must be taken to ensure that the final decision made is a good one. First, the problem or decision must be clearly defined. This involves specifying a goal. Second, one must state how the decision will be evaluated. This involves, for example, identifying performance measures. Third, the alternatives that are available with their contributions to the goal must be listed. This will involve considerations of constraints, such as time and money, that may make some alternatives infeasible. Fourth, one must show how well

each alternative satisfies the goal. Both qualitative and quantitative factors will need to be considered. Last, one alternative that best meets the goal must be chosen, or if a few alternatives may be done they need to be put in a priority order (16:35-51).

TAF completes most of these five steps. They have specified a specific goal of maximizing the R&M benefit while also trying to minimize the cost. The decision elements of the hierarchy tree are the performance factors by which the mods are evaluated. The alternatives have been identified, but some uncertainty in both the inclusion of all potential mods and the data for the mods does exist. TAF effectively shows how the alternatives satisfy the goal by using a model that assigns a value to each mod. Last, the mods are prioritized by the values assigned by the model. The only apparent problem that may exist is in the application of the model itself.

Making a Decision

This section addresses the three specific criteria that TAF needs to meet when making their decision on the mod prioritization. Each of these criteria will be discussed, followed by an analysis of how well TAF is meeting that critieria. The three specific criteria that TAF needs to consider are the acquisition of good data, identification of all alternatives, and correct valuation of the potential mods. Each one of these will be discussed in detail and in

the context of TAF's specific decision. It is vital that TAF meet the requirements imposed by each of these criteria to maximize the probability of a good outcome of their decision.

The data TAF uses must obviously be the data necessary to compare the mods. This means first that data must be available for each decision element in the hierarchy tree (i.e. reliability improvement and mod cost). Second, if the data is available, is it "good" data? In other words, the sources must be reliable, knowledgeable, motivated, and they must understand exactly what TAF needs so they supply accurate data. Third, TAF must understand the form of the data. For example, if they are concerned with reliability improvement for a certain situation, the data must be a measure of reliability improvement for the specific situation. TAF must be able to tell that the data is indeed what they were looking for.

TAF is able to acquire all the data necessary to do the comparisons among the mods. The data is fairly good in that it comes from a data system that was designed to provide information on maintenance and operational data (12:2-1). (This data set is discussed in detail in Chapter 4 in the section "Analysis of TAF's Use of the AHP"). As in any data set, there do exist some deficiencies and in this case the data set has a plus or minus 10% error built-in. This is due to various factors such as faulty reporting and paperwork avoidance (2). In spite of this problem, the data

set that TAF is using is probably the best source for the data they need. A second problem with the data acquisition is that there exists a possibility that TAF does not understand exactly what the data means. Due to the numerous definitions and measures of reliability and maintainability, for example, it is difficult to really understand what a certain piece of data actually means. TAF simply needs to work closely with the people who really understand the data base and extract that data appropriate for their needs.

The identification of all the alternatives, the potential mods, is crucial for TAF to have a valid prioritization of the mods. First, their method of collecting the mods must ensure that all those who have information on mods are contacted. Second, once these people are contacted, they must understand exactly what TAF needs and why so they understand the importance of the request for mods. Third, when all the alternatives have been identified, they must be defined specifically and precisely.

TAF very efficiently identifies all the potential mods. This is discussed in detail in the previous chapter in the section "TAF's Process to Develop the List". Recall that TAF contacts the using commands' system program managers for each of the TAF aircraft. These system program managers receive the proposed mods for their aircraft from the field units and the staff agencies of the major commands (5). Thus, both the people who actually maintain the

aircraft and the people who manage the aircraft are contacted in the search for mods. When the mods arrive to those collecting them, they are specifically and precisely defined by entries on the data worksheet. Each mod is assigned a unique mod number and an identification is made of the types and number of aircraft on which the mod may be done. There is also a word description of the mod. All these descriptions of the mod provide the necessary information needed to obtain correct data on the mod, which is ultimately the purpose of this requirement of precisely defining the mod.

The correct valuation of each mod is the most difficult criteria for TAF to meet. What this criteria means is that if mod A is preferred to mod B, the process that TAF uses to assign a value to each mod must give mod A a value that is higher than the value given to mod B. The process that TAF uses is the AHP, thus the AHP must yield values for the mods that are consistent with TAF's preferences for the mods. The way to prove this is by attempting to get results from the AHP that violate this requirement. Some possible areas that may be of concern are risk associated with certain mods, uncertainty in the data, and dependency between the mods.

TAF has assigned a value function to their problem which can be derived from their hierarchy tree. The function is:

$$(.301)*(\text{"RI"}) + (.301)*(\text{"MI"}) + (.098)*(\text{"IS"}) + (.201)*(\text{"MC"}) + (.099)*(\text{"LC"}) = \text{value}$$

where an entry in quotes means the value assigned to mod x in terms of that decision element, and RI = reliability improvement, MI = maintainability improvement, IS = inventory size, MC = mod cost, and LC = remaining life cycle. A detailed discussion of a case where this value function does not give a higher value to the mod that would be preferred by TAF is presented in the following chapter in the section "Improvement to TAF's Tree". To sum up the results of that example, mod A was preferred to mod B since mod A's life cycle cost savings were higher than mod B's, but the above value function gave mod B the higher value. In other words mod A was preferred to mod B but the value of mod A was less than the value of mod B. Thus, TAF does not satisfy this important criteria. However, the fix , which is explained later, is an easy one.

To sum up this section, TAF is doing a fairly good job at meeting the three decision criteria discussed. There exist some minor problems in the data area and a major problem in the valuation area. However, neither problem is too difficult to remedy and should not pose any large problems. A little refinement is all that is needed.

AHP Applicability

TAF uses the AHP to solve their problem of prioritizing potential mods. This section will first explain the type of

situation that normally exists for a proper application of this process. The appropriateness of TAF using the AHP in their specific situation will be discussed. Various decisions made using the AHP will be presented to demonstrate the process's wide applicability. This is followed by a brief discussion on the requirement that needs to be satisfied before a problem can be solved with the AHP.

The AHP is a "powerful process for tackling complex ... problems (20:22)". For this reason it has been applied in highly diverse areas. Almost all applications of the AHP involve rating decision alternatives and all applications involve some qualitative,as opposed to quantitative, elements that play an essential role in the decision problem (27:101). According to Grant,

> If there are multiple alternatives and if the irreducibles need to be given weight in the final choice, it is helpful to examine alternatives in pairs. It is much easier to reach a conclusion about the impact of a variety of irreducibles ... when the decision maker looks at only two alternatives at a time [8:296]

"The pairs comparison technique , [the method used in the AHP], it is claimed, utilizes the power of human judgment more effectively than ranking alternatives directly (25)". Since the AHP is based on the use of paired comparisons, we see that it deals well with problems that have qualitative, or irreducible, factors to consider. Most applications are "complex in that they involve a host of interrelated elements with varying degrees of impact on the decision (27:101)".

TAF's need to prioritize a given set of mods is indeed a complex problem. However, it is well suited for an AHP application. Similar to most of the other decisions that were made using the AHP, TAF's prioritization involves rating decision alternatives (i.e. the potential mods). It involves both quantitative and qualitative considerations. As discussed above, these situations are ones that the AHP is designed to deal with effectively.

The AHP has been used to solve numerous diverse decision problems in many different fields. For example, it has been used in business, personal and domestic planning, public policy planning, and economic policy planning, to name only a few. In the area of business, the AHP has been used to choose equipment, decide on leasing versus buying, choose a management candidate, decide on how to stagger industry hours for energy conservation, and decide on a plant location. In the area of personal and domestic planning, the AHP has been applied to decisions on choosing a car, a home computer, a career, an ideal investment, a school, and a house. (20:37-54) It is evident that there do exist many different types of decision problems that can successfully be solved by the AHP.

After an extensive literature review, only one restriction on the application of the AHP was found. An article by Kamenetsky states, "the AHP can only be applied to multiple-criteria decision problems in which the conditions for the existence of an additive value function

are satisfied (9:702)". The necessary condition for the existence of an additive value function is that the attributes (or decision elements) be mutually preferentially independent (9:705). This means that there must not exist any dependence between the branches of the hierarchy tree.

TAF's hierarchy tree as currently structured does have a hidden dependence between a couple of the decision elements that causes a dependence between the branches of the tree. (This is discussed in Chapter 4 in the section "Analysis of TAF's Use of the AHP"). However, the tree is easily restructured to eliminate the dependency (Chapter 4 in the section "Improvement to TAF's Tree"). Thus, TAF's problem can be solved using the AHP since it both fits the "typical" situation for which this process was designed and because it can meet the one restriction for using the process.

IV. Solution within the AHP Framework

This chapter, assuming that the analytic hierarchy process is a good methodology for TAF to use in solving their mod prioritization, focuses on the use of the process by TAF. The chapter is divided into three sections. The first section is a detailed description and critique of the separate steps of the analytic hierarchy process that TAF accomplishes. Several problems that exist in the TAF hierarchy tree are identified. The second section presents a new hierarchy tree for TAF to use that will correct some, but not all, of the problems with the tree they are currently using. The third section presents a much more extensive tree that takes into consideration all of the R&M 2000 goals, thus correcting more of the deficiencies associated with the current TAF tree.

Analysis of TAF's Use of the AHP

The next five subsections are an analysis of TAF's use of AHP. The structure of their hierarchy tree will be examined and potential problems with it will be explained. Next, the process of determining the weights TAF uses for the decision elements of the tree will be discussed and critiqued. Ideas on who should determine the weights will then be presented. The collection of the data and its presentation to the panel will be the next topic. The problems that exist in these areas are highlighted and

possible solutions are offered. The fourth section discusses the comparison step on the mods done by the panel members. Both positive and negative observations on the group's approach are presented. The last section discusses the model used by TAF to solve the comparison matrices in order to determine the value for each mod. This section also suggests ways the model improves TAF's final prioritization of the mods.

Tree Structure. Recall that the first step of the analytic hierarchy process structures the decision by constructing a tree. The objective of the decision appears at the top of the tree, the decision elements occupy the middle levels, and the alternative actions appear at the lowest level. TAF has set up their tree as depicted in Figure 3.

Two problems exist with the tree used by TAF. The first problem is caused by the process TAF uses to develop the tree. An article by Saaty states:

> ...[The] design of an analytic hierarchy - like the structuring of a problem by any other method - is more art than science. It necessarily entails substantial knowledge about the system in question. A very strong aspect of the AHP is that the individuals knowledgeable about the system ... who supply judgments to make the pairwise comparisons, also play a prominent role in specifying the hierarchy [21:205].

Thus, the panel members, who possess the required knowledge about the various systems, should be helping to develop the tree. Unfortunately, only one person in TAC SMO-R&M does this structuring of the problem. The panel members only

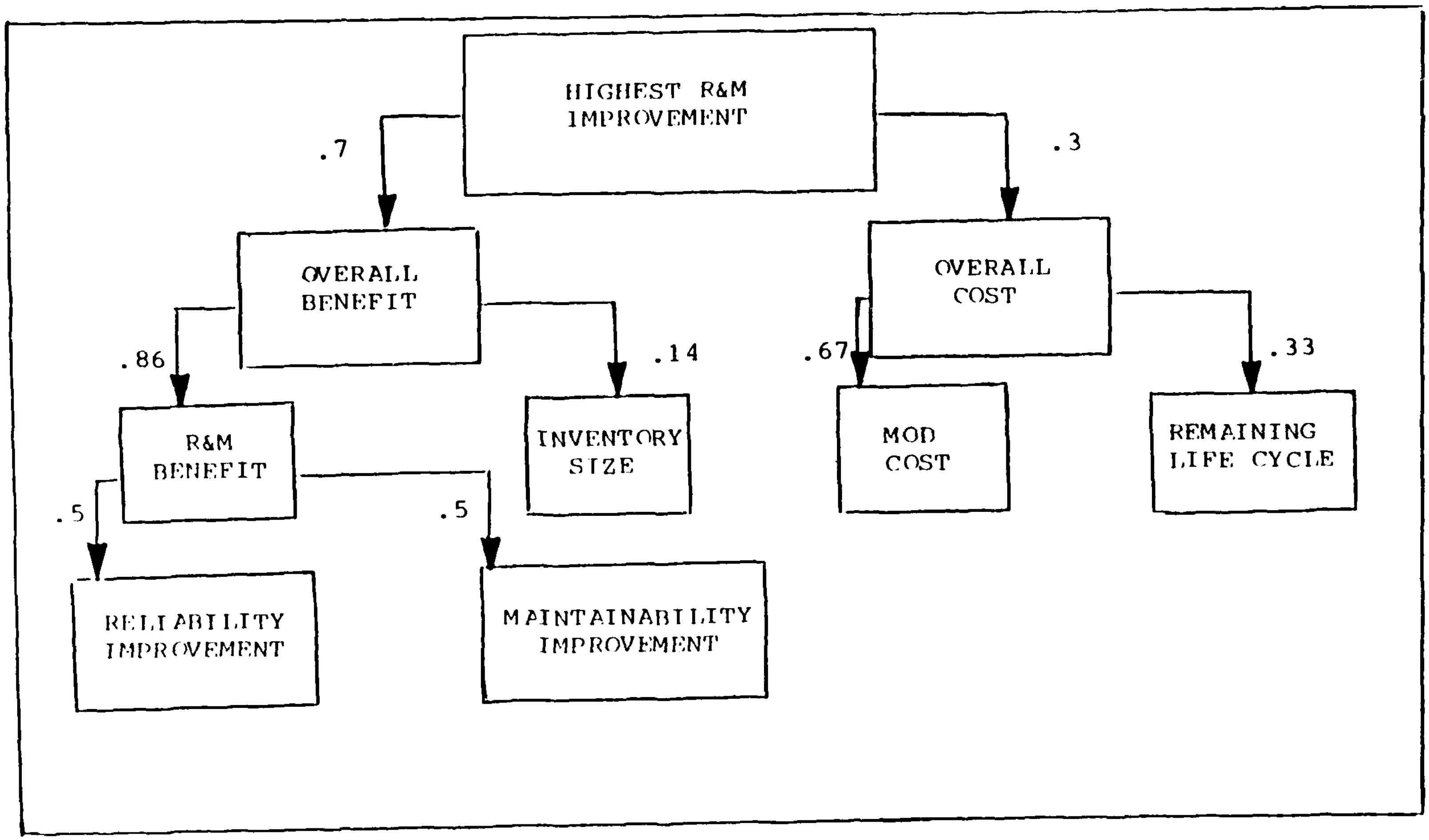


Figure 3. The Current TAF Tree (TAFTREE)

agree or disagree on what is presented to them. Although the panel members do have input in this way, it is passive versus the active participation advocated by Saaty.

The second problem involves some of the actual decision elements in the tree. Specifically, the inventory size and the remaining life of the system are important characteristics of the mods to be considered, however, they are directly tied in with the "mod cost" decision element. For example, the inventory size (# of aircraft) will affect the total cost of the mod since:

Total mod cost = (mod cost/aircraft) * (# of aircraft)

Thus, the greater the inventory, the more money is spent. However, TAF currently considers a large inventory size as desirable since the research and development cost per mod will be reduced. Looking at the total mod cost, TAF should prefer a small inventory size, but looking at only the research and development cost, TAF should prefer a large inventory size. Which one is the right preference? This confusion is easily eliminated by simply realizing what TAF's ultimate goal is when considering the cost of a mod. They want to minimize the cost. Thus, TAF should consider the total mod cost and prefer the mod with the smaller total mod cost.

Next, consider the decision element of "remaining life of the system". This element also directly relates to cost in the following manner:

Total LCC savings = (LCC savings per year) * (remaining life) where LCC is life cycle cost savings. If TAF is concerned with the cost, or in this case the cost avoidance, then the total LCC savings is a better measure of the amount saved than the remaining life of the system. For example, consider two mods. Mod A may save $10/year and its remaining life is 10 years. Thus, its total LCC savings is $100. Mod B may save $20/year, but its remaining life is only 5 years. Mod B's total LCC savings is $100. These mods would be rated equal in terms of total LCC savings, which TAF is ultimately concerned with, but mod A would be preferred to mod B if only the remaining life was considered. It is important to take into account both the amount saved per year as well as the remaining life of the system, and both of these are embodied in the total LCC savings calculation.

Having accepted the new ideas of total mod cost and LCC savings as being the data that TAF should actually be considering, there is one more step to be done. The present value of both the life cycle cost savings and the mod cost must be calculated. Then the present value mod cost will be subtracted from the present value total LCC savings. This figure will yield the net present value life cycle cost savings. This figure would be the only one the panel would need to consider to accurately take the mod cost, inventory size, and remaining years left for the system, into account.

(The details of using this approach will be addressed in the section "Improvement to TAF's Tree").

Tree Weights. Once the decision elements have been decided upon and the decision hierarchy tree has been set up, the next important step is to decide the weights for the branches on the tree which are associated with the decision elements. Currently, prior to the panel meeting where the comparisons between the mods are made, people from the R&M shops for the various Tactical Air Force aircraft coordinate on the weights for the decision elements. These weights are decided upon by a single person in TAC SMO-R&M (5). This person is not the actual decision maker, but rather the analyst who reports to the decision maker. However, the choice of the weights for the decision elements is a task that should be accomplished by the decision maker who has the ultimate responsibility for the prioritized list that is developed. By developing the weights, the decision maker has fixed the relative importance he feels exists between the various decision elements. In other words, he has input information to the AHP that indicates his opinion on the importance of the various decision elements. Thus, although he will not be involved with the time consuming task of comparing the data on the mods, (this is done by the panel memebers), he has not lost his decision making authority because he has already had his turn at structuring the problem. Due to this fact, the decision maker will be more inclined to accept the results of the analysis.

Looking ahead to the section "Improvement to TAF's Tree", and assuming that TAF accepts this new hierarchy structure, one sees that there are only two decisions on weights that the decision maker needs to make. First, he must decide how much importance to attach to R&M improvement versus the overall cost of the mod. Second, he needs to decide how much weight to attach to reliability improvement versus maintainability improvement. Even though there are only these two sets of weights to determine, it is very possible that the decision maker may not be completely sure of the weights he assigns. This should not pose a big problem since sensitivity analysis can be done. In a later section, "Analysis of TAF's Use of the AHP", the sensitivity analysis that is performed on the Planning and Programming Priority Project (P4) model is discussed. Thus, the decision maker can specify a weight of .7 plus or minus .1 for the R&M improvement and .3 plus or minus .1 for the overall cost. The P4 model would then be run using the following weights:

	Run 1	Run 2	Run 3
R&M improvement	.7	.6	.8
Overall cost	.3	.4	.2

The results for each run (i.e. the prioritized list of mods) would then be available for the decision maker to make his final determination of the proper prioritization of the mods.

Data and its Presentation to the Panel. Prior to the meeting for the panel members, TAF completes worksheets containing information on R&M improvement, R&M ranking, inventory size, mod cost, and the remaining life of the system. The first two areas of information are requested from the Maintenance and Operational Data Access System (MODAS). Inventory size and mod cost are figures supplied from the Air Logistics Centers functional managers. Data on the remaining life of the system is contained in the TAC/XP planning documents (5). This information is then used in the comparison of the mods. This sounds very straightforward, but there are some critical problems that exist in both the data and the manner in which it is presented to the panel members.

The primary problems in the data collection lie in MODAS itself and the interpretation of its data by TAF. MODAS is a "central, on-line, interactive data storage and access system for the storage and processing of maintenance and operational data on selected USAF weapon systems (12:2-1)". MODAS unfortunately has a plus or minus 10% built-in error (2). Thus, the panel members may be misled if they fail to recognize this fact. (A discussion of this appears in Chapter 5).

The area of R&M improvement is considered so the panel member can determine which mods will supply the most increase in R&M. For example, when comparing two mods on reliability improvement, the panel considers the difference

between the reliability of the component prior to the mod versus the projected reliability of the component after the mod. The mod with the biggest improvement is thus the preferred mod. TAF uses the mean time between maintenance (MTBM) in this comparison. They must realize that MTBM measures only the logistics reliability whereas mean time between critical failure (MTBCF) measures the operational reliability (2). Depending on what TAF feels is more important, they may want to reconsider which measure of reliability improvement to use. When considering maintainability improvement, TAF looks at the maintenance manhours per flying hour (MMH/FH). Unfortunately, MMH/FH data is not valid at the component level (2). The measure TAF should use is mean time to repair (MTTR) for the component, but MODAS only supplies this data indirectly. The actual figure must be calculated by hand after drawing out the appropriate data from MODAS (2). Thus, TAF may not be pulling out the appropriate data from MODAS to do their mod comparisons on R&M improvement.

The area of R&M ranking is included to provide the panel member with information on how critical the component is to the R&M of the system. Thus, if component A is more critical to its system than component B, (i.e. component A's improvement would increase the reliability or maintainability of its system more than the improvement of component B) then mod A will carry more weight and be preferred over mod B. MODAS provides information for the

worst systems, worst 50 subsystems, and worst 100 work unit codes, which are referred to in this discussion as components. The data is generated from the latest 3-month fleet MTBM for the reliability ranking and by MMH/FH for the maintainability ranking (12:8-2). A component having a ranking of 1 would be the component in the system that causes the system to fail the most. This is done looking at both the reliability of the system and also at its maintainability. TAF's idea to use the MODAS data is good, except that it overlooks one important point. Namely, if a component is ranked as the worst component in terms of reliability and mod A is done on it that projects to increase the reliability by 400%, perhaps it would still be the worst component in terms of reliability. However, a different component may be the second worse in terms of reliability and by performing mod B, thereby increasing MTBM by only 10%, it falls into the ninth worse ranking position. In this situation TAF would have given mod A more weight than mod B since mod A had a worse ranking. However, mod B would probably be the better choice and should have been given more weight than mod A. Thus, it is important to consider how critical the component is, as well as to consider how much its criticality will be reduced by performing the mod.

Fortunately, MODAS provides a table that makes this task straightforward. The data in the following table can

easily be taken from the Worst Case Reliability Report (12:A3-2).

Component	MTBM(*)	Ranking
1	100	1
2	200	2
3	300	3

(*) old MTBM measured in hours

In this case, component 1, with an MTBM of 100 hours, is ranked as the worst component in the system because it causes the system to experience a "type one" failure most often (i.e. every 100 hours) (12:8-2). One need only consider the new projected MTBM for a component and see if the ranking for that component will improve. For example, if you are considering component 1 and it has a projected new MTBM of 200 hours, then its ranking has moved to position 2. This is an improvement of 1. However, if the new MTBM is 150, it will not change its ranking at all. Thus, the panel should not only consider the current ranking, but also the new ranking for the component after the proposed mod is accomplished.

A secondary problem of the data collection rests in the information gathered for the mod costs. The per year costs will be assumed to be good, but they are not put into present value terms. This may cause faulty cost comparisons to be made by the panel. (Details of the

problem this creates will be discussed in the section "Improvement to TAF's Tree").

When the data is collected it is provided to all the panel members in the form depicted in Figure 4. This form makes it clumsy for the panel members to compare the mods. A preferred format, containing the same information but making it easier to compare the mods is shown in Figure 5. Notice that all the potential mods are listed down the left side of the sheet. The mod name and mod number are listed across the top. The entries of life remaining, number in inventory, reliability improvement and reliability ranking, maintainability improvement and maintainability ranking, and total cost would separately be entered in the row entry titled "decision element". Thus, there would be one data worksheet for each decision element. This format has the advantage of providing all the information needed for each comparison on a single sheet of paper. Thus, the members can quickly discern the high and the low values and have a more solid grasp of the range of the values involved. This is critical for the consistency of the comparisons done with the analytic hierarchy process. (This concept will be discussed in detail in Chapter 5).

Comparison Step. Armed with the data on the mods and a hierarchy tree with all the decision elements weighted, the panel is ready to make the pairwise comparisons of the mods. There are several points to be made about the panel and how

R&M COST BENEFIT ANALYSIS

REQUEST

MOD NAME: Self Explanatory (S.E.)   MOD #: S.E.

MDS: S.E.   # PLANES TO BE MOD'D: S.E. (TAC & USAF TOTAL)

DESCRIPTION OF MOD: S.E.

POM YR: FY90

RELIABILITY IMPROVEMENT: Current MTBF

Projected MTBF

MAINTAINABILITY IMPROVEMENT: Current MTBM

Projected MTBM

RELIABILITY RANKING: Ranking in top 100 MTBF,

Example: 22 Ranking Factor: 20.9

MAINTAINABILITY RANKING: Ranking in top 100 MMH/FH

Example: #16 Ranking Factor: 21.6

TOTAL FLEET COST/YR: FY89

FY90 .35M for TAC $42.2 for USAF

FY91

FY92

TOTAL FLEET INSTALLATION COST (Hours): FY89

FY90 1500 for TAC, 159 for USAF

FY92

Figure 4. Current Data Worksheet

	Mod name	Mod #	Decision Element
Mod 1			
Mod 2			
Mod 3			
. . .			
Mod n			

Figure 5. New Worksheet for the Data

it functions. First, the panel consists of people who are familiar with the various TAF aircraft systems on which the mods will be done. They are the "experts". The panel assembles in a conference room where they go through all the necessary comparisons between the mods. Each panel member is given the chance to say what his score is for each comparison, for example that mod A is moderately better than mod B in terms of reliability improvement. He is also given the chance to explain his reasons for the score. When every member has had his turn, the panel chairman assigns the final score for that comparison (5).

The manner in which the panel operates has some positive points and some negative ones. Looking first at the positive side, an article by Quade states that :

> When working with individual experts, it is important to insist that each one make the logic behind his opinions or judgments explicit. For only when the reasoning is explicit can someone else, whose information and perspective may be different, use the work of the first to modify his own opinion [16:328].

Since each member of the panel can not possibly be aware of all the details of all the TAF aircraft systems, the open exchange of rationale for scoring mods performed by the panel is indeed necessary. Thus, TAF is right on the mark in this respect.

Another comment by Quade on the idea of using experts efficiently states that providing an effective means of communication among experts is critical. A common frame of reference is important to this communication and an ideal way to enforce it is by presenting the problem to the experts "in terms of an analytic model, or even better, to have them participate in formulating the model as well (16:329)". The model in TAF's case is the hierarchy tree within the AHP. Although currently the panel does not have a lot of input in developing the model, they do understand its meaning (5). The fact that a model exists at all is the important point to consider, since it enables TAF to fulfill the need for a common frame of reference. Each decision element in the tree is explicitly defined and explained to each panel member so that in a discussion about reliability improvement, for example, everyone is talking about the same thing. However, on the negative side, Quade goes on to say that:

> Experiments have shown that the best use of a number of experts is not the traditional method of having the issues presented to them and debated in open round-table discussion until a consensus emerges or until they arrive at an agreed upon group position [16:328].

He feels that committees often fail to make their assumptions and reasoning explicit and that one needs to avoid the psychological drawbacks of a round-table discussion (16:328). Since the TAF panel performs in the round-table setting described by Quade, there is the chance for some undesirable outcomes. For example, some members' opinions may be swayed by others who are more verbal about their opinions, but who also unfortunately may not have all the pertinent facts. The panel can not be performing optimally if this happens.

Getting Logical Answers. Recall that the AHP will yield a value under each decision element for each mod using the data generated from the pairwise comparisons. These values are then aggregated up the hierarchy producing an overall value for each mod. These final values are then used to rank the mods (22). TAF uses the Planning and Programming Priority Project (P4) model to solve for the values of each mod.

The P4 model supplies two types of information. First, the mods with their corresponding values are given. Second, the consistency ratio at each decision element node and the overall consistency ratio indicates how good the comparisons are. A value of less than .1 is a good consistency ratio (22). To illustrate consistency, consider a comparison of mod A, mod B, and mod C. If the panel states that mod A is equal to mod B, and that mod A is moderately better than mod

C, then they should say that mod B is moderately better than mod C. If they do this their consistency ratio will be 0 (the best value), but if they say mod B is equal to mod C their ratio will get worse. Thus, the panel can make all their comparisons and P4 will highlight the comparisons (if any) that are unsatisfactory by yielding a high consistency ratio (i.e. >.1). The panel can then go back to their comparison and check their work.

The P4 model also has the capability to easily change the structure and/or the weights of the tree. This allows for sensitivity analysis to be done quickly (22). Thus, if there exists some doubt as to what the weight of inventory size should be, the P4 model can show graphically what new weights (higher or lower) for inventory size would change the ranking of the mods. Consider that the inventory size weight is currently set at .2 and you have a plus or minus .05 bound on this. If you must change it to .7 or .01 to change the mod ranking, then the panel would not need to be too concerned if they put the weight at .15, .2, or .25 as the weight for inventory size.

Due to the facts that TAF uses a model to calculate the values for the mods, that a consistency check is done, and that sensitivity analysis is performed, the final values for the mods, and thus their ranking, will be satisfactory. This assumes that the P4 model does in fact solve the comparison matrix data correctly, and that the data used in the comparisons is good.

Improvement to TAF's Tree

This section will present a new hierarchy tree for TAF to use in prioritizing its mods. The structure of the tree, as well as the rationale for the structure, will be discussed. The additional data required by this tree will be explained and possible data sources mentioned. Last, an example of the difference in the values of the mods using TAF's current tree and the new tree will be illustrated.

Structure. The structure of this new tree (NEWTREE), Figure 6, is very similar to the TAF tree (TAFTREE). The main goal of the decision remains the same: to receive the highest R&M improvement with the least cost. The next level is also the same. This level consists of the two decision elements "overall benefit" and "overall cost". However, "overall benefit" has been renamed "R&M improvement". This is where the similarities end.

The decision elements "inventory size", "remaining life cycle", and "mod cost" have been eliminated from TAFTREE. The information they contain has not been lost, but rather included in the "overall cost" decision element. The "overall cost" reflects the net life cycle cost savings realized by performing the mod. The details are explained later in the data section. The decision elements of "reliability improvement" and "maintainability improvement" remain, however, their interpretation is different. TAFTREE considers the predicted improvement in R&M that is supplied by the people proposing the mods. Therefore, if mod A

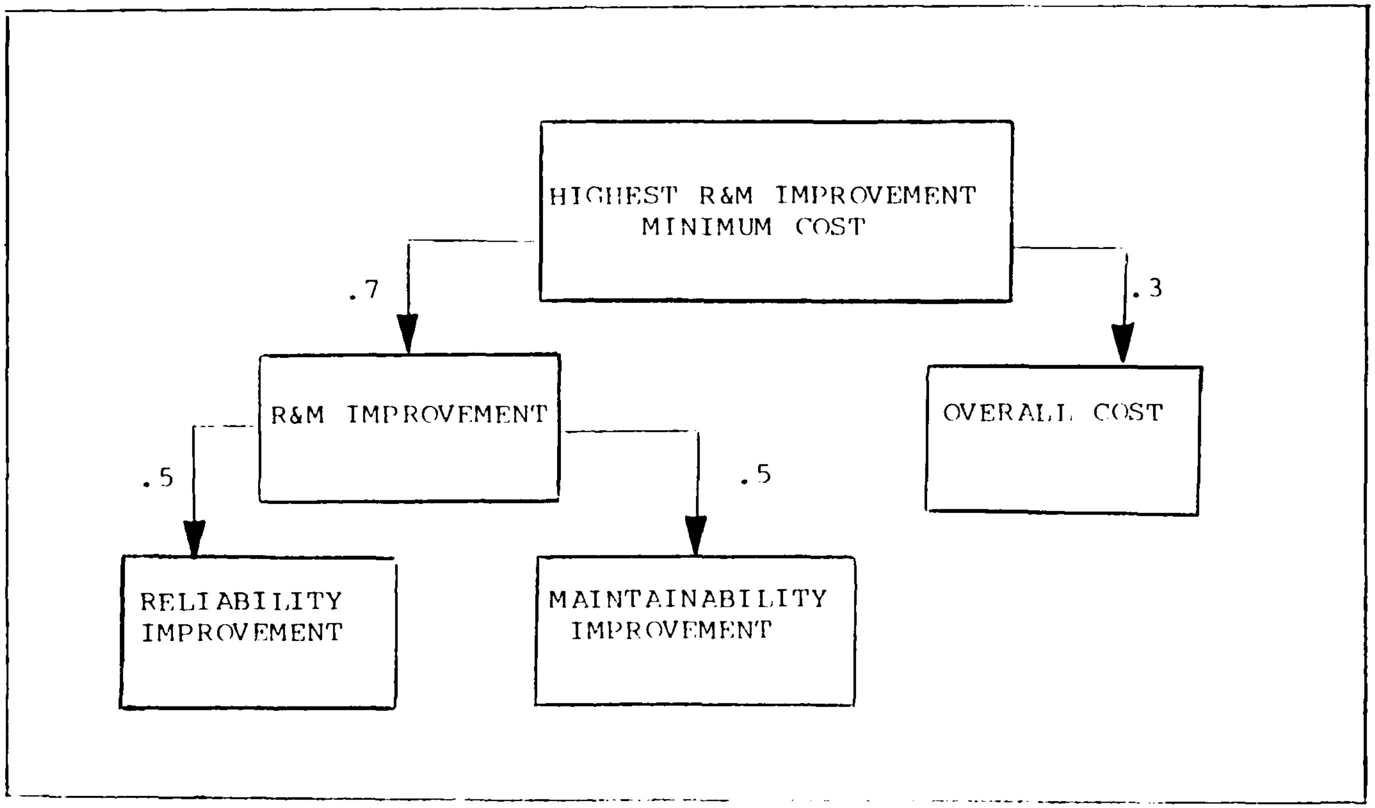


Figure 6. Improved Tree (NEWTREE)

improved its MTBM by 100 hours and mod B improved its MTBM by 50 hours, then mod A is twice as good as mod B in terms of reliability improvement. NEWTREE will consider the predicted improvement of the component while also considering the required improvement (i.e. the improvement in the MTBM of the component which will cause it to not be a critical player in the MTBM of the system). Thus, if mod A needed 50 hours improvement in MTBM and it achieved 100 hours, there is an overkill of 50 hours. In addition, if mod B needed 50 hours improvement in MTBM and it achieved this figure, then there would be no overkill. NEWTREE would rate mod A equal to mod B in this scenario even though mod A has a greater increase in MTBM. The determination of the required MTBM improvement will be discussed later in the data section.

Data. To use the NEWTREE versus the TAFTREE structure, TAF will need a few more pieces of data and a new way of looking at data they already have. The later case occurs for the "reliability improvement" and "maintainability improvement" decision elements. Take "reliability improvement" for example. Currently TAF considers the hours improvement in MTBM and the reliability ranking of the component in the system. Consider components A, B, and C which are all in the same system. The following table supplies the data known about each component. The MTBM hours are the absolute MTBM values for each component.

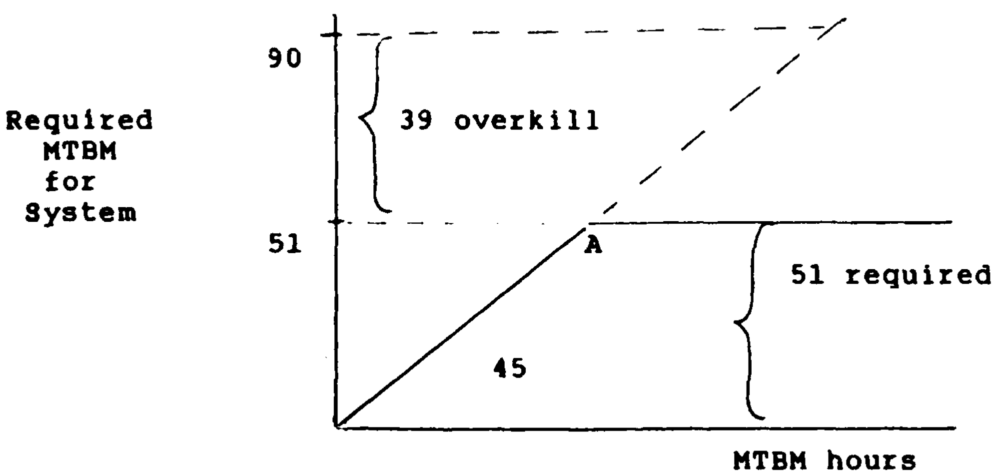
Assume that component A is the only one with a potential mod.

	Current Reliability Ranking	MTBM (current hours)	MTBM (predicted hours)
Component A	1 *	10	100
Component B	2	60	60
Component C	3	75	75

* = worst case

TAFTREE looks at the reliability ranking and at MTBM(predicted)-MTBM(current). This is the only information they use to make the comparisons among the mods. NEWTREE will look at the reliability ranking and see what improvement in MTBM will improve its ranking (i.e. give it a higher ranking). For example, an improvement of 51 hours for component A will move it into position 2 in the reliability ranking. An improvement of 66 hours will move component A into the third position. Someone will need to determine what change in the MTBM of the system is desired as the new required standard. Then, a specific mod for that system, with its predicted improvement in its MTBM, will be evaluated on how well it achieves this new standard (i.e. the system MTBM). Say the decision maker decides that a system MTBM of 60 hours is the new required standard. In this case component A would have 90 hours improvement in reliability, but only 51 hours are required. Thus, there is

an overkill of 39 hours. NEWTREE will not consider the overkill, but rather take the 51 hours as the reliability improvement for component A. A graph may explain this point better. Consider the graph below where the possible MTBM hours for component A are shown on the horizontal axis and the required MTBM improvement (i.e. the amount needed to move past the next critical component) is shown on the vertical axis. The data point for the reliability improvement of component A that TAF will use to make the pairwise comparisons is the maximum possible point on the possible MTBM line (in this case point "A"). Note that this line does not extend all the way to 90 hours MTBM, but is cut short by the required amount of 51 hours MTBM.



Note that although this analysis only gives credit for partial mods (i.e. it disregards the improvement that is overkill), the mod would still have the full predicted improvement in MTBM. The data for the reliability ranking

and MTBM(current) is available in MODAS and the MTBM(predicted) is submitted by the system program managers. The same is true for the maintainability improvement data.

Another set of data needed for NEWTREE arises in the "overall cost" decision element. It is here that some new data will need to be obtained. This value for each mod is defined as: Net present value of life cycle cost savings=

PV (Total life cycle cost savings) - PV (Total mod cost)

where PV stands for present value. The mod cost per aircraft per year figures are already available, so it is a simple matter to calculate its present value. The PV total mod cost =

$$\sum_{1}^{n}\left[\frac{\text{mod cost/AC/year(1) * (\# aircraft)}}{(1.07)^{0}} + \frac{\text{mod cost/AC/year(2) * (\# aircraft)}}{(1.07)^{1}} + \ldots + \frac{\text{mod cost/AC/year(n) * (\# aircraft)}}{(1.07)^{n-1}}\right]$$

where n = # of years to do the mod and AC = aircraft. The discount rate used in this calculation is 7%. The rationale for using this value is discussed below. Note that if the constant total mod cost was calculated, the equation would be:

constant total mod cost=

$$\sum_{i=1}^{n}\left[\text{(mod cost/aircraft/year(i)) *(\# aircraft)}\right]$$

where n= # of years to do the mod.

The life cycle cost savings are a bit trickier. However, the item managers could calculate the dollars saved per year as a result of the mod (5), although they have not done this in the past. Taking this figure and multiplying it by the inventory size (i.e. # aircraft) will yield life cycle cost savings per year for all the aircraft. Knowing the remaining life cycle for the various aircraft types, one could then discount the stream of yearly savings back to the present value amount. This figure would be the present value of the life cycle cost savings.

present value total life cycle cost savings=

(LCC savings/year/mod)*(# aircraft)*(P|A,7%,n)

where n= # years left for the aircraft
(P|A,7%,10) = 7.024
(P|A,7%,20) = 10.594
(P|A,7%,30) = 12.409

However, the constant total life cycle cost savings=

(LCC savings/year/mod)*(# aircraft)*(# years)

The final step calculates the net PV LCC savings which is calculated by (PV total LCC savings - PV total mod cost). The net constant LCC savings is calculated by (Constant total LCC savings - Constant total mod cost).

The only other new piece of data needed is the appropriate discount rate to use when calculating the net present value of the life cycle cost savings and the mod cost. According to Lt Col Russel,

> The Treasury borrowing rate on long-term securities is correctly the time value of money for defense analysis. With this position, today's ... correct rate for discounting constant dollar streams is 7.0% [18:9].

Improvement. Using the NEWTREE versus the TAFTREE structure has three advantages. First, since there are fewer decision elements to be considered for each mod, there are fewer comparisons that need to be made by the panel members. Second, the "political factors" of "inventory size" and "remaining life cycle" are incorporated into the decision element of "overall cost' and thus are not as visible. The third, and the most important, advantage is that the prioritized list of mods more accurately reflects TAF's goal of minimizing cost by correctly dealing with the mod cost and the life cycle cost savings. In other words, NEWTREE considers the present value of the net LCC savings versus TAFTREE which only considers the constant LCC savings. Following is a sample comparison of the prioritized lists generated from the TAFTREE and the NEWTREE structures. Note that the weights used for the decision elements are the same in the two trees.

The data shown below which was used for the four mods presented in this example is representative of real world data. The equations for calculating the constant dollar and present value amounts presented earlier were used to arrive at some of the values in the following table. Using this data, the following comparison matrices for the TAFTREE and NEWTREE structures were developed. These matrices are developed by using the teeter-totter shown below.

Table 1. Data Used to Show Improvement

	Mod 1	Mod 2	Mod 3	Mod 4
# of planes	98	654	367	200
life remaining (years)	20	20	10	30
reliability improvement (hours)				
raw	2	50	600	400
need	2	50	100	100
reliability ranking	4	10	25	100
maintainability improvement (hours)				
raw	10	-	200	50
need	10	-	100	50
maintainability ranking	30	40	2	25
mod cost/aircraft/year(i) (constant/present value)				
1	2/2	4/4	10/10	10/10
2	2/1.86	2/1.86	2/1.86	10/9.35
3	5/4.37	1/.87	2/1.75	5/4.37
4	10/8.16	1/.82	2/1.63	2/1.63
5	10/7.63	-/-	1/.76	2/1.53
total mod cost (constant/present value)	29M/24.02M	8M/7.55M	17M/16M	29M/26.87M
life cycle cost savings/year/mod	2M	10M	8M	5M
total life cycle cost savings				
constant	3920M	130800M	29360M	30000M
present value	2076.4M	69284.6M	20622M	12409M
net cost savings				
constant	1078M	125568M	23121M	24200M
present value	-276M	64346M	14750M	7035M

Mod A	A	VS	S	M	E	M	S	VS	A	Mod B

In this diagram, E means that mod A is equal to mod B. On the left side of the diagram, an A means that mod A is absolutely preferred to mod B, a VS means that it is very strongly preferred, an S means that it is strongly preferred, and an M means that it is moderately preferred. On the right side of the diagram, the same definitions hold, but now mod B is preferred to mod A. There are also preferences located between those shown, for example a rating of M-S means that a mod is moderately to strongly preferred.

TAFTREE Comparison Matrices

RI	1	2	3	4
1	E	E	1/VS	1/S
2	E	E	1/VS	1/S
3	VS	VS	E	S
4	S	S	1/S	E

MI	1	2	3	4
1	E	E	1/A	1/M-S
2	E	E	1/A	1/M-S
3	A	A	E	VS-A
4	M-S	M-S	1/VS-A	E

IS	1	2	3	4
1	E	1/A	1/S	1/M
2	A	E	S-VS	VS-A
3	S	1/S-VS	E	M
4	M	1/VS-A	1/M	E

MC	1	2	3	4
1	E	1/VS	1/M	E
2	VS	E	M	VS
3	M	1/M	E	M
4	E	1/VS	1/M	E

LC	1	2	3	4
1	E	E	M	1/M
2	E	E	M	1/M
3	1/M	1/M	E	1/VS
4	M	M	VS	E

NEWTREE Comparison Matrices

RI	1	2	3	4
1	E	1/S	1/A	1/A
2	S	E	1/S	1/S
3	A	S	E	E
4	A	S	E	E

MI	1	2	3	4
1	E	E	1/A	1/S
2	E	E	1/A	1/S
3	A	A	E	S
4	S	S	1/S	E

COST	1	2	3	4
1	E	1/A	1/M	1/E-M
2	A	E	VS	A
3	M	1/VS	E	E-M
4	E-M	1/A	1/E-M	E

Note that RI stands for reliability improvement, MI for maintainability improvement, IS for inventory size, MC for mod cost, LC for life cycle remaining, and COST for total net life cycle cost savings.

Using a software package called Expert Choice (7), these matrices were solved to yield the values for the mods. A table depicting the mods and their associated values at several of the decision elements is provided below. For each decision element, the values for all of the mods will sum to one. The highest value for each decision element is given to the mod that is best in terms of that decision element.

Notice that the final prioritization of the mods is the same for both trees, but the values for the four mods are different. Thus, although in this case the mod ranking is the same, it is possible that for another example the ranking (based on the mod values) could be reordered. The reason for the different mod values is a consequence of both

a different tree structure and the reinterpretation of some of the decision elements within the tree. One sees the most change in the values of the mods under the "overall cost" decision element node since this is where the most drastic adjustments were made to the TAFTREE structure.

Decision Element	TAFTREE		NEWTREE	
	mod	value	mod	value
RI	3	.640	3	.424
	4	.235	4	.424
	1	.063	2	.114
	2	.063	1	.037
MI	3	.724	3	.669
	4	.166	4	.220
	1	.055	1	.055
	2	.055	2	.055
COST	2	.471	2	.721
	4	.234	3	.141
	3	.177	4	.084
	1	.118	1	.055
final goal	3	.481	3	.425
	2	.244	2	.276
	4	.200	4	.251
	1	.075	1	.049

Further Improvement to NEWTREE

A further enhancement to NEWTREE would incorporate the idea of aircraft mission importance into the structure of the decision. This will allow for two changes. First, the mission importance of each aircraft relative to the others may be shown. Second, the "reliability improvement" and

"maintainability improvement" decision element weights may vary for the different aircraft mods. Thus, this builds in more flexibility for the decision maker. To reflect this change, the tree has been expanded to include "R&M" decision elements for all the TAF aircraft. Thus, there could be branches for the F-4, F-15, F-16, A-10, F-11, E-3, EC-135, and the EC-130. The weight for each of these "R&M" nodes is (1/Number of TAF aircraft on which mods are being done) if the mission importance is the same for each aircraft type. However, if the mission importance of each aircraft is different, then the weights may reflect this fact (see Figure 7). The only requirement is that the weights sum to one. Under each of these "R&M" decision elements are the "reliability improvement" and "maintainability improvement" decision elements. The panel members will thus compare R&M improvement for all the mods within a certain aircraft type. They must use the same scale for all these comparisons, however, so that their mod values will be compatible. (see discussion on weighting in Chapter 5).

Ideal R&M 2000 Tree

Although the new hierarchy tree proposed in the previous section is an improvement over the one currently used by TAF, it is not the ideal one. This section will suggest a hierarchy tree that considers all of the R&M 2000 goals. Due to its complexity, only some ideas on the

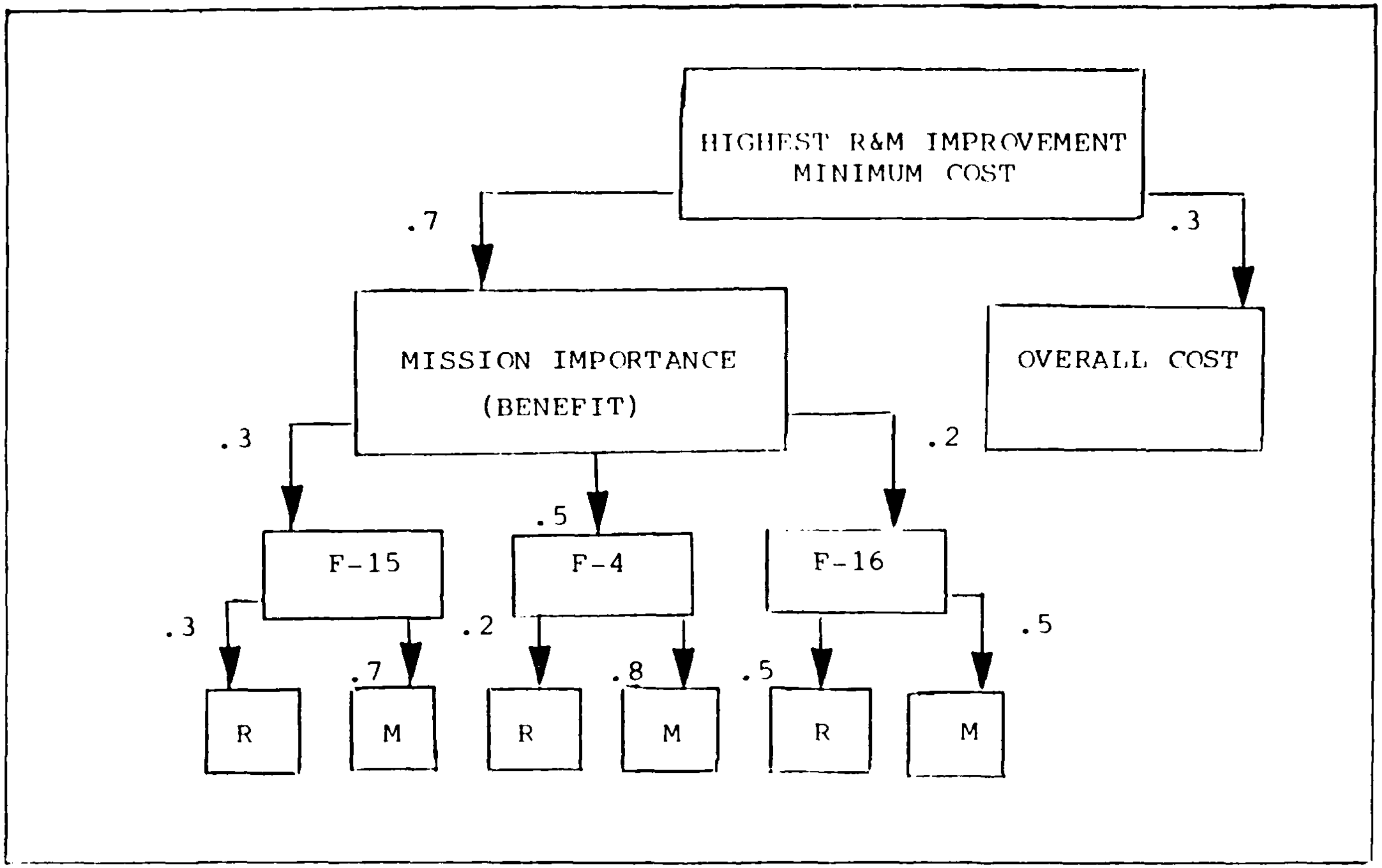


Figure 7. Tree for Further Improvement of TAF's Tree (NEW2TREE)

structure of the tree and the data it will require will be presented.

First, one needs to recognize the goals of the R&M 2000 plan. R&M 2000 hopes to increase war fighting capability, increase the survivability of the combat support structure, decrease the mobility requirements per deploying unit, decrease the manpower requirement per unit of output, and decrease costs (24:v). Notice that the tree used by TAF only directly addresses the cost issue and very indirectly addresses the other four issues. Thus, the TAF tree needs to be considering much more. The first two levels of the tree would be as shown in Figure 8. The main goal is to satisfy the R&M 2000 goals. These five goals constitute the second level of the hierarchy.

Given the five decision elements of the tree, quantitative criteria have been developed to measure progress toward their achievement. These criteria were devised considering: the relevance to the wartime mission, conformity to existing data systems and reports data, suitability to contract requirements, administration, and warranties, and feasibility considering technology and cost (24:I-5). These criteria are depicted in the following table.

One will quickly notice that reliability and maintainability are the most prevalent criteria to be considered. However, each goal is ultimately considering a different aspect of R&M. For example, the war fighting

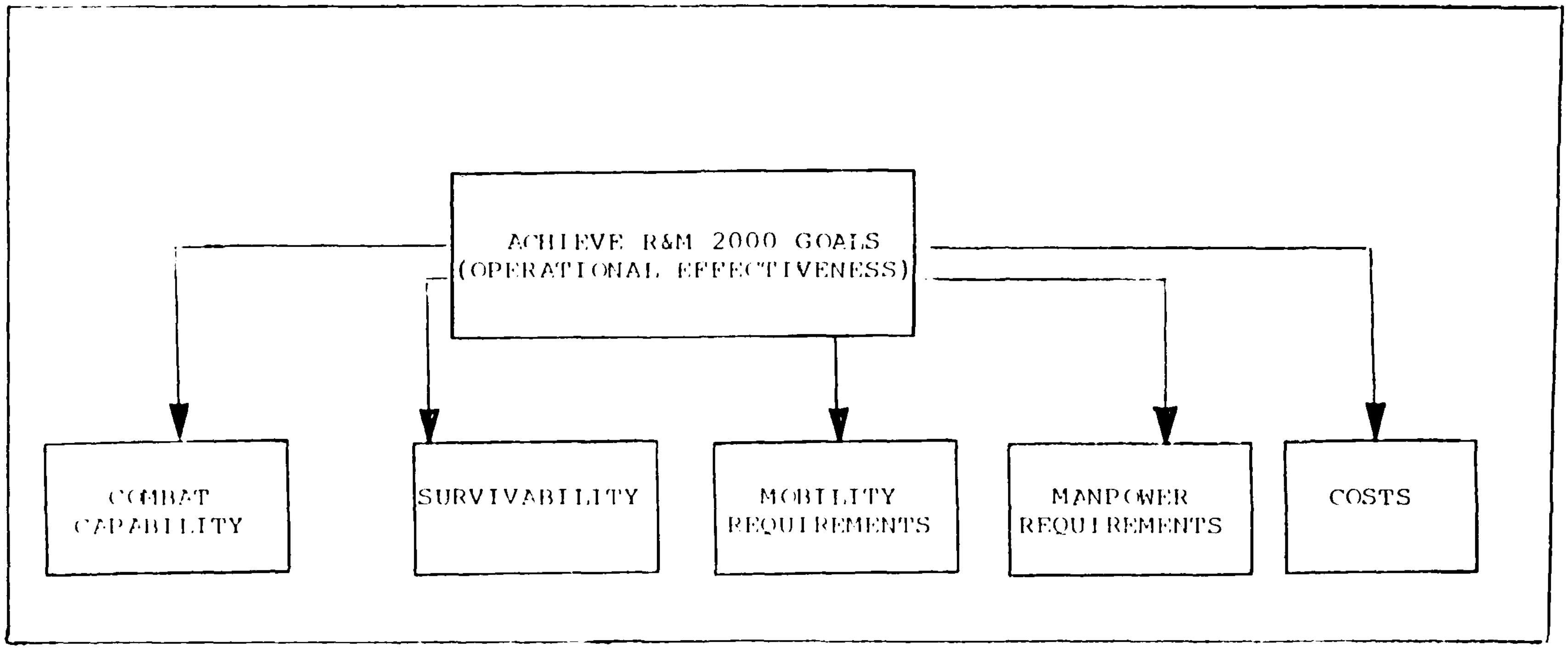


Figure 8. R&M 2000 Tree

Table 2. R&M 2000 Goals and Criteria

Goal	Criteria
war fighting capability	reliable (MTBCF) maintainable
survivability	eliminate need for intermediate support facilities
mobility	reliable (spares, SE, personnel)
manpower	reliable maintainable-less personnel
cost	reliable maintainable-lower LCC

capability goal is concerned with the mean time between critical failure, whereas the mobility goal is concerned with how reliability can reduce the number of spares, support equipment, and personnel. Going into a bit more detail, let's consider each goal separately in terms of what data should be considered when comparing the mods.

The warfighting capability goal may need to consider the percent decrease in the number of critical failures, mean downtime, mission capable rate, combat reliability, or availability. The main question that needs to be answered is: How can I capture the contribution of R&M mods to combat capability?

The survivability goal may need to consider what parts, support equipment, and personnel requirements are eliminated

by performing the mod. Also to be thought about is the elimination of the need for intermediate support facilities.

The mobility requirement goal is a bit more involved than the survivability goal. What is important is a decrease in the size, weight, or both size and weight, of the spares, support equipment, and personnel needed. The number, size, and weight of spares and support equipment will need to be determined. Also, the decrease in the number of personnel required will need to be known. Then, the total volume and/or weight saved by performing the mod can be calculated. To be considered when doing the calculations is the scenario you are dealing with (i.e. are you concerned with the savings for a 30 day war or for one individual break?). Also a concern may be the fact that certain spares, support equipment, and personnel are shared which may affect the calculations or their meaning.

Another tricky goal to work with is the one to decrease manpower requirements. If the break rates are decreased and the repair time is decreased, obviously the manpower requirements should decrease. Thus, one needs to consider the mean manhours per operating hour, the mean repair time, and the combat reliability rate. To complicate matters, rules may exist stating that there must be a certain number of people working certain repairs for safety reasons. What needs to be done is show how all these different pieces of data fit together to yield a good measure of the new manpower requirements for the mod.

The measure for the cost goal should be relatively straightforward to develop. First, the mod cost and life cycle cost savings per year need to be determined. Then the present values of these streams of expenses and savings need to be calculated using an agreed upon discount rate. The final step is to subtract the present value of the expenses from the present value of the savings in order to get the net present value of savings.

Even though most of the five decision elements of this R&M 2000 tree boil down to one equation that needs to be developed to compare the old system to the new one, it is clear that the data needed to evaluate each mod's contribution to the goals is quite extensive. However, the task of data acquisition may be simplified greatly with the use of a new model developed by Synergy (5). This model, called SCOPE MOD, will provide data on the warfighting capability, manpower requirements, deployment requirements, and life-cycle costs of the proposed mods versus their baseline cases (17). Thus, soon the ideal R&M 2000 tree may be quite easy to acquire data for and subsequently appropriate to use in prioritizing the mods.

V. Problems within the AHP

Given that TAF uses the AHP correctly, they are still in danger of committing some errors that are hidden within the AHP. Three of these AHP drawbacks will be discussed in this chapter. The first one centers around the issue of dependency among the mods. The second problem addresses the fact that the AHP cannot deal with uncertainty. The last problem occurs in the comparison step and involves the need for a consistent comparison scale.

Dependency

The issue of dependency among the mods is one that TAF is likely to encounter. Consider, for example, two mods that may be done on the radio of the F-16 aircraft. The first mod proposes to replace certain components of the current radio with more reliable ones. The second mod proposes to replace the entire radio. Obviously, only one of these two mods will be undertaken. We call these mods dependent. It is acceptable that TAF consider both of these mods when they perform the comparisons of all potential mods. The prioritized list will give the mods in preferred order, and the first mod in this set of two dependent mods will be chosen. The reduced prioritized list will thus consist of all the original independent mods and the higher valued of the two dependent mods. The problem that may now occur is that if the AHP is run on this reduced set of mods,

their order may be changed to yield an incorrect ordering. An illustration of this point follows.

Consider four mods that need to be prioritized. There are two dependent mods, mod A (new radio components) and mod D (new radio). Mod B is a new radar and mod C is a new brake system. Performing the AHP on these mods with two decision elements, cost and benefit, the following pairwise comparison matrices are developed. Note that "E" means that the mod in the row is "equal" to the mod in the column, an "A" signifies that the mod is "absolutely preferred", and "1/A" means that the mod in the column is "absolutely preferred" to the mod in the row.

cost	A	B	C	D
A	E	A	A	A
B	1/A	E	E	E
C	1/A	E	E	E
D	1/A	E	E	E

benefit	A	B	C	D
A	E	1/A	E	1/A
B	A	E	A	E
C	E	1/A	E	1/A
D	A	E	A	E

Running these comparison matrices on Expert Choice (7) using the tree that assigns the weight of .4 to cost and .6 to benefit, yields the following vector of mods with their associated values.

Mod	Value
A	.330
B	.303
C	.303
D	.063

Assume now that we take out mod D since it is dependent on mod A, which is the higher valued mod. The prioritized order of mods should now be A,B,C. However, if these mods are run on the same tree with the same comparison matrices (minus the comparisons done on mod D) since "it is reasonable to assume that the decision maker would still consider the criteria to be of equal importance (1:228)", the vector of the mods with their associated values is:

Mod	Value
B	.527
A	.382
C	.091

Note that the order is B,A,C versus A,B,C we would have expected. This new order for the mods A, B, and C is the correct order if only these three mods were in the original set of potential mods. However, mod D was also a potential mod that was dependent with mod A and when mod D was included in the pairwise comparison matrices a different ordering of the mods A, B, and C occurred. Thus, since the ordering of these three mods changed when one mod was deleted, obviously there is a problem with the method the AHP uses to solve the pairwise comparison matrices.

To clarify the concern here, consider the following example. Assume you have an apple, an orange, a banana, and a peach and you need to rank them in order of preference. When you consider all four pieces of fruit the preferred

order is peach, orange, apple, banana. Now, take away the orange as a potential choice. You would then say your preferred order is peach, apple, banana. In this situation, however, the AHP may yield a preference order of apple, banana, peach. This is where the problem is.

There are two ways for TAF to handle this inconsistency. First, TAF may deal with this problem by simply being aware of the possibility that if they run the AHP on the reduced set of mods, the ordering may change. If they are only concerned with the order of the mods, and not in the final value for the chosen mods, the easiest solution would thus be to take the first prioritized list, which included all the mods, and use it to list their mods in order of preference. On the other hand, if TAF needs the correct values associated with each mod, they will need to handle the problem in a manner prescribed by Belton.

Belton's article states that "the only aspect that has changed is the normalization factor (1:229)", so the only way to explain the reordering (inconsistency) is in the second step of the AHP. It is in this step that the "vectors which denote the relative importance of options with respect to individual criteria are normalized so that their entries sum to one (1:229)". Saaty's method normalizes the vectors so they sum to one, whereas Belton's article advocates normalizing the eigenvectors so the maximum entry is one. For example, given the following matrix:

$$\begin{bmatrix} 1 & 1/9 & 1 \\ 9 & 1 & 9 \\ 1 & 1/9 & 1 \end{bmatrix}$$

Saaty's technique calculates the vector by a two step process. First, each entry is divided by its column total. This yields the following normalized matrix:

$$\begin{bmatrix} 1/11 & 1/11 & 1/11 \\ 9/11 & 9/11 & 9/11 \\ 1/11 & 1/11 & 1/11 \end{bmatrix}$$

Second, each row is summed up and divided by the number of entries in the row. This yields the vector (1/11, 9/11, 1/11). In contrast, Belton's method normalizes the eigenvectors of the original matrix so that "the maximum entry is one rather than the entries summing to one (1:229)". This technique yields the following normalized matrix:

$$\begin{bmatrix} 1/9 & 1/9 & 1/9 \\ 1 & 1 & 1 \\ 1/9 & 1/9 & 1/9 \end{bmatrix}$$

Summing each row of this normalized matrix and dividing by the number of entries in the row yields the vector (1/9, 1, 1/9).

Notice that the two vectors resulting from Saaty's and Belton's normalizing techniques differ. This different vector calculated with Belton's technique will preserve the correct order of the mods when the dependent mods are deleted from consideration (1:229). What TAF needs to do is change the P4 model to reflect this new way of calculating the mod values. They will then run the model on all the

mods and determine which of the dependent mods is dominated by the other mod. This dominated mod will then be eliminated and the model will be run again so that the values for the mods that are still being considered can be determined. The mod order yielded from this run will be the same as the order yielded by the first run with all the mods considered, except of course the eliminated mod will not be listed.

Uncertainty

"Decision making requires the study of uncertainty (10:449)". Kamenetsky states that the AHP is applied to "multiple-criteria decision-making problems under certainty (9:705)". The AHP does not consider any uncertainty. If there is uncertainty that can be ignored, then this will not pose a problem. But, usually there does exist some uncertainty in a decision, and the decision made by TAF is no exception. They may need to consider the uncertainty in their data, (i.e. in their costs and R&M improvements on the mods) and perhaps even the uncertainty of war. An illustration of how uncertainty can contribute to the AHP yielding an incorrectly prioritized list of mods will be used to explain the problem. First, a direct application of the AHP will be done on four potential mods. Second, a decision analysis type application, which considers uncertainty, will be done on the same four mods. Third, a

comparison between the outcomes will be made to show AHP's shortcomings in this area.

AHP Application. The AHP tree is a simple one consisting of only two decision elements. Benefit is the first element with the weight of .7 and cost is the second with the weight of .3. The data needed on the four mods will be the benefit, which will be assumed equal for all four mods, and the life cycle cost savings for each mod. The data on the cost savings are found in the following table. The median value is the value that TAF would normally use when making comparisons between the mods. The low and high values reflect uncertainty in the true life cycle cost savings. The degree of the uncertainty may be a function of how much new technology needs to be developed, fuzziness about the actual materials needed and what their cost will be, and uncertainty in how well the mod will actually work . Thus, a mod that will require some unknown materials and new technology will have a large spread between the low and high costs. If all goes well and the materials required are readily available, then the low cost may be achieved. However, if the technology does not develop as anticipated and the materials needed are scarce, the higher end of the cost estimate may be quickly reached. However, a mod that is using developed and proven technology and knows what materials will be needed will not have a large spread between the low and high cost estimates.

Mod	Life Cycle Cost Savings (dollars) low	median	high
1	255	260	390
2	700	870	880
3	150	270	400
4	650	780	1200

Using this data there are three ways to use the data to implement the AHP. First, consider the low dollar savings. In this case, the mod order (best to worst) would be 2,4,1,3. Second, the high dollar savings could be used which yields the order of 4,2,3,1 for the mods. Third, the median value could be used. This provides a mod list of 2,4,3,1. Using the different approaches may obviously yield different prioritized lists.

Decision Analysis Application. Using the approach to solving a decision analysis problem as explained in The Principles and Applications of Decision Analysis by Howard and Matheson (11:47-52), the decision tree is set up as shown below in Figure 9. Note that there is a 50% chance that the life cycle cost savings will be at its medium value and a 25% chance it will be at its high or low value. Also note that the value function is determined by the dollar savings. The expected value of the mods are given in the following table.

Mod	Expected Value
1	291.25
2	830.00
3	272.50
4	852.50

The value for mod 1 was calculated by:

$$(.25)*(255) + (.5)*(260) + (.25)*(390) = 291.25$$

Ordering the mods from high to low the mod order is 4,2,1,3.

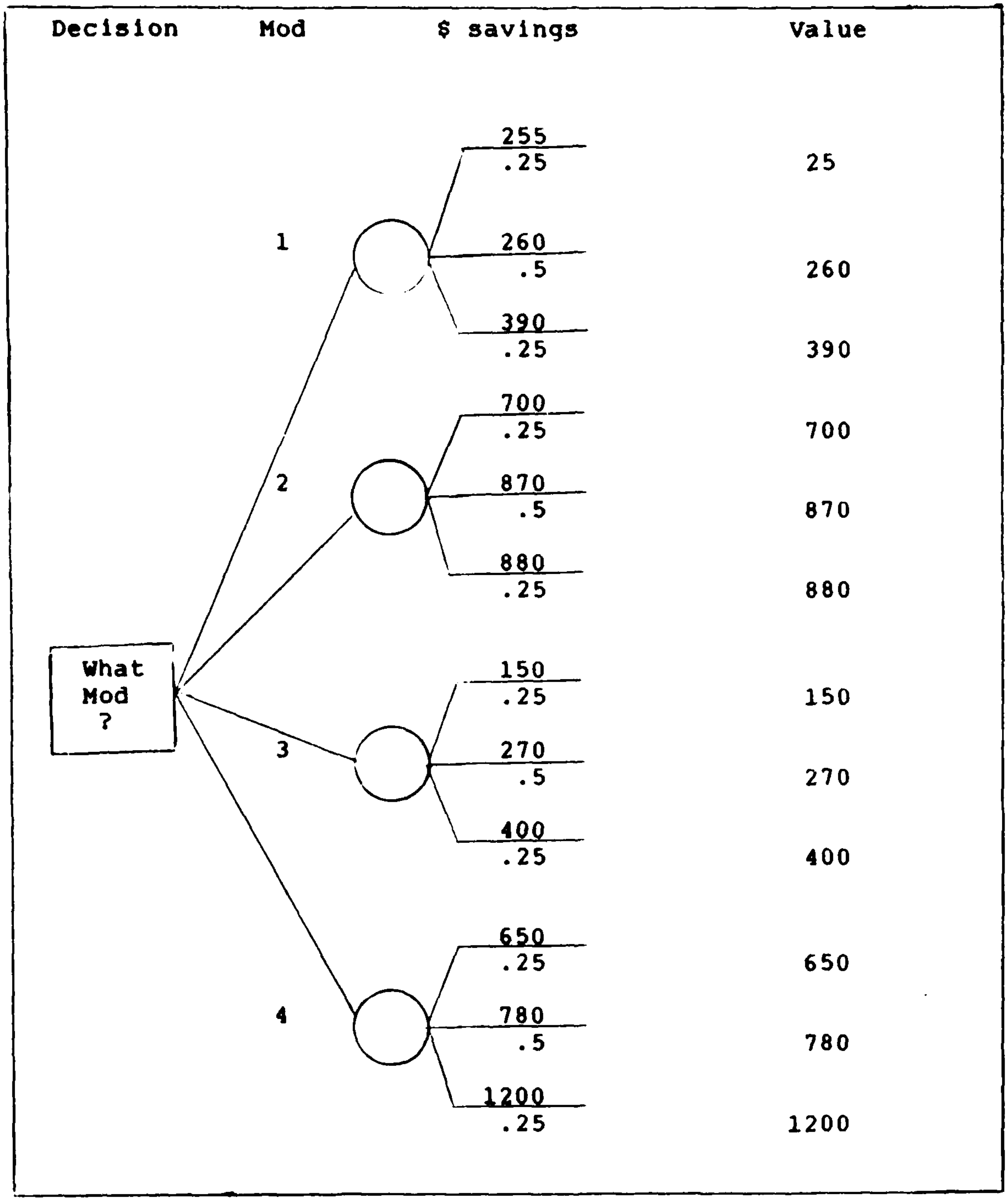


Figure 9. Decision Tree for Example

Comparison. The following is a summary table of the various mod prioritizations yielded by the two approaches of the AHP and decision analysis.

Table 3. Prioritizations Yielded by the AHP and DA

Approach	Mod Prioritization			
AHP				
low	2	4	1	3
high	4	2	3	1
median	2	4	3	1
Decision Analysis	4	2	1	3

One can readily see that the rankings are not very consistent. The decision analysis ranking is the only one that considers the uncertainty in the data explicitly. Notice that none of the AHP prioritizations yield the same answer. Therefore, when uncertainty is present TAF may consider calculating expected values for the uncertain data. These expected values would then be used when the panel performs the pairwise comparisons of the mods.

Comparison Scale

The AHP requires that the same "scale" be used for decision elements on the same level. By "scale" we mean the range used on the teeter-totter that is referenced when making the pairwise comparisons to determine the relative importance of one mod versus another. If the same scale is

not used, the AHP results may not be valid. A simple example will clarify what the potential problem is.

Remember that the teeter-totter we are referring to is symbolized by the following.

Mod A	A	VS	S	M	E	M	S	VS	A	Mod B

In this diagram, E means that mod A is equal to mod B. On the left side of the diagram, an A means that mod A is absolutely preferred to mod B, a VS means that it is very strongly preferred, an S means that it is strongly preferred, and an M means that it is moderately preferred. On the right side of the diagram, the same definitions hold but now mod B is preferred to mod A. There are also preferences located between those shown, for example a rating of M-S means that a mod is moderately to strongly preferred.

In this discussion, the "large scale" will refer to the full range of values (i.e. the whole teeter-totter). The "small scale" will refer to only a half of the scale (i.e. the values between and including the "S" rating).

The simple decision among four mods that will be illustrated has mod cost and mod reliability as its two decision elements. Both are weighted equally. Pairwise comparisons using the "large scale" yield the following comparison matrices.

cost	A	B	C	D
A	E	1/VS	M	1/M
B	VS	E	A	S
C	1/M	1/A	E	1/S
D	M	1/S	S	E

reliability	A	B	C	D
A	E	VS	S	VS
B	1/VS	E	1/M	E
C	1/S	M	E	M
D	1/VS	E	1/M	E

Solving these matrices using Expert Choice (7), yielded the following values for the mods.

Mod	Value
A	.376
B	.367
C	.118
D	.139

Thus, the prioritized list is A,B,D,C.

The same comparison matrix for the cost was used in the next run of Expert Choice (7), but the reliability matrix was cnanged. This matrix was adjusted to the "small scale" versus the "large scale" of the cost matrix. For example, if mod A was rated "S" versus mod C, the new matrix changes the rating to a "M". The following conversion table was used to make all the changes in the reliability matrix.

Large Scale	=	Small Scale
E		E
M		E-M
S		M
VS		M-S
A		S

The resulting comparison matrix for reliability is shown below.

reliability	A	B	C	D
A	E	M-S	M	M-S
B	1/M-S	E	1/E-M	E
C	1/M	E-M	E	E-M
D	1/M-S	E	1/E-M	E

Solving for the mods using the "large scale" for the cost and the "small scale" for the reliability yielded the following values.

Mod	Value
A	.316
B	.389
C	.133
D	.162

Thus, the prioritized list is now B,A,D,C.

Notice that when the reliability matrix was changed from the large scale to the small scale, the mods' priority changed. The reason for this inconsistency is alluded to by Watson. His article on assessing attribute weights states that "if a change of scale is made on one attribute of a multiattribute value function, then the weight must change on that attribute, to preserve the order induced by the value function (26:583)". In our illustration, the value function is represented by:

$$.5(\text{cost}) + .5(\text{reliability})$$

When the scale on reliability was changed, we would have needed to change the coefficient for that attribute in the value function to preserve the mod order.

For example, when the large scale was used on both comparison matrices the mod order was A,B,D,C. However, when the scale on the reliability branch was changed to the small scale, the mod order was B,A,D,C. To convert the B,A,D,C order back to the A,B,D,C order (the correct order

since it was obtained when the same scales were used to make the comparisons) we would need to change the coefficients of cost and reliability in the value function. Thus, perhaps a weight of .4 for cost and .6 for reliability would convert the B,A,D,C order to A,B,D,C.

This changing of the weights can get very confusing, but luckily it is not necessary for TAF to do this. The only thing they need to do is remember to use the same scale (i.e. the large scale that ranges from "E" to "A") when doing the mod comparisons. The easiest way to accomplish this is by considering the best and the worst mod for each particular decision element. The value of the worst mod is subtracted from the value for the best mod. This difference is then divided by four (the number of increments on the teeter-totter). This quotient is the amount that each increment on the scale stands for. Thus, if the quotient is 100 and mod A has a value of 200 and mod B has a value of 100, then mod A will be rated as moderately better (one increment) than mod B. Thus, this method provides an easy way to compare the mods and also assures that the best mod when compared to the worst mod for any specific decision element will receive a rating of "A". This forces the large scale to always be used (since the "A" value is guaranteed to appear in every comparison matrix), and the requirement is thus satisfied.

It should be pointed out that the tendency to use a small scale will usually arise when comparing data that is

very close. For example, if the life cycle cost savings for four mods are 10, 11, 12, and 13, then the comparison matrix might be similar to the following since the values are not vastly different from one another.

LCC	1	2	3	4
1	E	1/E-M	1/M	1/M-S
2	E-M	E	1/E-M	1/M
3	M	E-M	E	1/E-M
4	M-S	M	E-M	E

The matrix may even look like the following to reflect no difference between the mods with respect to life cycle cost savings.

LCC	1	2	3	4
1	E	E	E	E
2	E	E	E	E
3	E	E	E	E
4	E	E	E	E

However, if the large scale is used, the following matrix would be developed.

LCC	1	2	3	4
1	E	1/M	1/S	1/VS
2	M	E	1/M	1/S
3	S	M	E	1/M
4	VS	S	M	E

Notice that the matrices are different, and as discussed above, this may cause inconsistency in the final values for the mods.

VI. New Techniques

This chapter discusses new techniques that TAF might consider using to prioritize their potential mods. The techniques of goal programming, a proxy approach to multi-attribute decision making, Data Envelopment Analysis, and a multiattribute decision making by sequential resource allocation, were all considered as potential methods for TAF to use in their mod prioritization problem. However, none of these techniques were found to be suitable. Goal programming is not set up to solve TAF's type of decision problem. For example, it will indicate how many of each mod to do, given certain constraints, but this is not what TAF needs to know (i.e. TAF needs to rank the mods) (14:518). The proxy approach is "practical for decision making under certainty (15:687)", thus it would not help TAF to deal with their uncertainty. The Data Envelopment Analysis is an "efficiency measurement methodology (3:2)", and is not at all applicable to TAF's situation. The sequential resource allocation, like goal programming, is in a format that is not suitable for use by TAF (13).

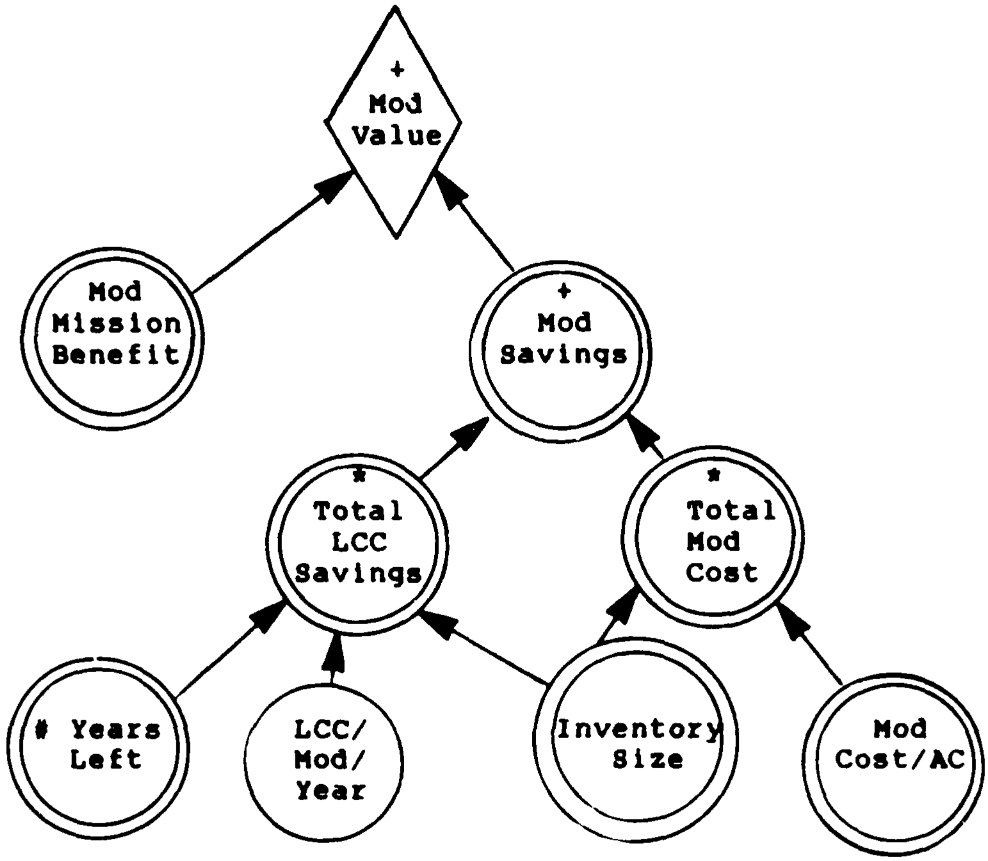
However, two techniques were found that are suitable for use by TAF. The techniques of decision analysis (DA) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) will be explained. First, the methodology of each technique is presented. This is followed by an example of how TAF might apply the technique

to their specific problem of prioritizing potential mods. Last, a brief discussion on the improvement that can be realized by using the technique versus the AHP will be given.

Decision Analysis

DA is a "procedure that can be applied to any decision susceptible to logical analysis (11:27)". It is iterative and comprised of three phases. The first phase is the deterministic phase. In this step "the variables affecting the decision are defined and related, values are assigned, and the importance of the variables is measured without any consideration of uncertainty (11:26)". In the second or probabilistic phase, probability assignments on the variables are made and risk preference is introduced. "The third, or informational, phase reviews the results of the last two phases to determine the economic value of eliminating uncertainty in each of the important variables in the problem (11:26)".

Using these steps an approach for solving TAF's prioritization problem is described below. The problem has been simplified to consider only three mods. The first step is to build the model (see Figure 10) that is used to obtain an expected net present value for each mod. These values will then be ordered high to low to prioritize the mods. The decision diagram shows the relationship between the



where a "*" indicates a product of the variables
"+" indicates a sum of the variables
"AC" stands for aircraft

Figure 10. Decision Diagram

variables that will determine the value function. In the diagram we see that the mod value (enclosed in the diamond) is determined by summing the values of the mod mission benefit and the mod savings. In this example we will assume that the mission benefit will be fulfilled with or without the mod and thus will only consider the mod savings and how it influences the value of the mod. This value will actually be the "expected" net present value of the mod

since the uncertainty in the data will be considered. In the diagram, the variables that are certain are enclosed by a double circle, whereas the uncertain variables are enclosed by a single circle. The only uncertainty in this example concerns the life cycle cost (LCC) savings per mod per year.

Note that the decision diagram depicted in Figure 10 is an influence diagram. Software exists to solve for the expected net present value of models constructed in this manner.

The second step is to assign probabilities to the uncertain variable. The probabilities will normally be determined by consultation with experts in the related areas. Arbitrary probabilities are used in this example. Their values appear below.

	Probabilities
LCC Savings	
High	.25
Median	.50
Low	.25

The third step is to calculate the expected net present value of each mod using the mod value function. In this example, the value for each mod is calculated using the following relation.

Value of a mod = mod savings =

total LCC savings - total mod cost=

(LCC savings/mod/year)*(inventory size)*(# years left) - (mod cost/aircraft)*(inventory size)

This relation is depicted in the decision diagram.

The following data is used for this example.

Mod	LCC/mod/year high	median	low	mod cost/AC	inventory size	# years
A	40	35	20	40	100	20
B	30	25	20	30	150	20
C	60	40	10	50	100	10

To solve for the value of each mod, the uncertainty in the LCC savings/mod/year will be accounted for by using the following equation.

Value of a mod =
[.25(LCCL*inv size*# years) + .5(LCCM*inv size*# years) + .25(LCCH*inv size*# years)] - (mod cost/AC*inv size)

where LCCL is the low LCC savings, LCCM is the median LCC savings, and LCCH is the high LCC savings. Note that in these calculations the simplification of assuming a zero discount rate has been made. This eliminates the need to use a more complicated equation to calculate the mod value (see the discussion in Chapter 4 in the section "Improvement to TAF's Tree"). Also, note that software exists to find the expected net present value for each mod given the model in an influence diagram form as in Figure 10. The calculated values for the mods A, B, and C appear below.

Mod	Value
A	61,000
B	70,500
C	32,500

Therefore, the mod order is B,A,C.

There are two reasons TAF may want to consider using DA. First, DA is able to "represent the uncertainty that inevitably permeates a decision problem (11:24)". This

paper (Chapter 5) already made the point that the AHP does not deal with uncertainty, which is one of its major shortcomings. The decision problem TAF faces does contain uncertainty in the data, and DA will handle this uncertainty correctly. Second, by putting all the values (i.e. both the mod savings and the mod mission benefit) in terms of dollars a firm foundation for analysis is provided. It is straightforward to compare mods when their values are reduced to one common measure (i.e. dollars) that is understandable to all. The decision process as explained above still requires some work, especially in the area of developing a way to express the mission benefit in terms of dollars so the expected net present value of the mod will also be in dollars. However, once this task is successfully accomplished, TAF would be able to use DA to prioritize their mods.

PROMETHEE

The PROMETHEE is a "new class of outranking method in multicriteria analysis (4:228)" that is used to select and rank projects. The new method was introduced by Roy and includes two phases. The first phase constructs an outranking relation on a finite set of actions. This involves defining a preference index for the decision maker which determines the outranking relation. The second phase exploits the outranking relation in order to yield an answer that "maximizes the multicriteria problem

Max {f1(a),...,fk(a) | a an element of the set K} where K is a finite set of actions and fi i=1,...,k, are k criteria to be maximized (4:228)".

An illustration of an example application will help to explain the PROMETHEE. Consider the multicriteria problem of ranking three mods (A,B,C). Three criteria are considered relevant to the decision maker: f1:reliability improvement, f2:maintainability improvement, and f3:LCC savings. For each criterion, a criterion type (generalized criteria) indicating the preference function of the decision maker must be specified. There exist six types of generalized criteria (4:229-232), five of which have parameters that are specified by the decision maker. For our example we will assume all the criteria have the same generalized criteria, which will be the "usual criterion". The usual criterion assigns the value of one to a comparison between two mods if there exists a difference between them, and a zero if no difference exists. Thus, "there is indifference between A and B if and only if the value of A equals the value of B. As soon as the two evaluations are different the decision maker has a strict preference for the action having the greatest evaluation (4:229)".

The data gathered on the three mods is shown below.

Mod	LCC savings	RI	MI
A	40	20	15
B	40	10	5
C	20	20	10

where RI stands for reliability improvement and MI stands for maintainability improvement. Using the data and considering the preference function explained above, the calculations on the preference index are made. The preference index is:

$$\tilde{\Pi}\,(a,b) = \Big(\sum_{i=1}^{k} \Pi_i\, P_i\,(a,b) \Big) / \Big(\sum_{i=1}^{k} \Pi_i \Big)$$

where Π_i is a weight denoting the relative importance of criterion fi. In this example, Π_1 =.35, Π_2 =.35, and Π_3 =.3. Using this information, the following table is developed.

	A	B	C	sum of row
A	-	.65	.65	1.30
B	0	-	.35	.35
C	0	.65	-	.65
sum of column	0	1.30	1.00	

For example, the entry for A versus B is calculated by [(.35)*(0) + (.35)*(1) + (.3)*(1)] / [(.35) + (.35) + (.3)]=.65

The sum of the column is now subtracted from the sum of the row for each mod, yielding the values:

mod A = (1.3)-(0) = 1.3

mod B = (.35)-(1.3) = -.95

mod C = (.65)-(1) = -.35

Thus, the ranking of the mods (high mod value to low mod value) is A, C, B.

The advantage of using this method as compared to using the AHP is that it may avoid the sensitivity to small changes that is experienced with the AHP. This problem (as discussed in Chapter 5) may cause the ranking to change when there are small changes made in the comparisons. Specifically, if a small scale is used, one ranking will be obtained and if the large scale is used, a different ranking may be obtained. In the PROMETHEE, "some small deviations in the determination of these values [the parameters for the different preference functions] do not often induce important modifications of the obtained rankings (4:228)". Since the decision maker cannot usually fix the exact values for the parameters, this "stability problem is of a major importance (4:235)". However, the parameters should have an economic significance which should help the decision maker to fix them more easily and precisely (4:236). TAF may decide to implement the PROMETHEE since it is simple, clear, and stable. Further work would need to first be done on determining the correct preference functions and parameters for each of the criterion functions, but once this is accomplished, the rest would be straightforward.

VII. Conclusions and Areas for Further Research

Conclusions

This thesis has two main thrusts. First, a validation of TAF's decision making process to prioritize their R&M modifications is done. Second, two alternative methods to solve this same problem are presented.

Validation. This thesis presents a three part validation of the decision making process TAF uses to prioritize their R&M mods. The first part of the validation focuses on the general steps TAF must perform and three specific criteria TAF must meet to ensure their final decision made is a good decision. TAF does not satisfy these requirements in two areas. First, the data from MODAS needs to be more fully understood. Second, the value function for the mods needs to be improved upon so that it always assigns a higher value to the mod that TAF prefers. However, these areas of deficiency may be easily corrected. The applicability of the AHP to TAF's specific decision problem is addressed and the analysis indicates that the problem is ideally suited for an application of the AHP

The second part of the validation accomplishes an [illegible] depth analysis of TAF's application of the AHP. The structure of the hierarchy tree is shown to conta[illegible] problems. Two of the decision elements ("inver[illegible] and "remaining life of the system") both affe[illegible]

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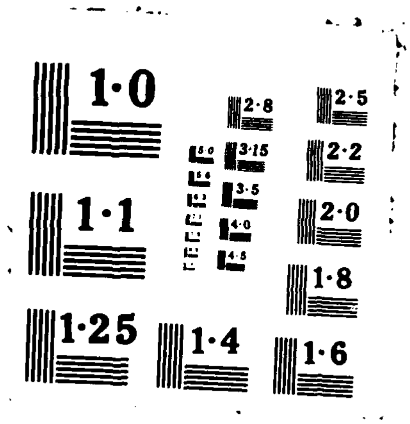
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decision element. A new tree is presented that restructures TAF's tree by combining these three decision elements into one. The current TAF tree also fails to consider all five of the R&M 2000 goals. Another tree is presented that incorporates these goals, and ideas on the data necessary to evaluate mods using this tree are discussed.

The third part of the validation presents three areas contained within the AHP that may pose problems for TAF. The area of dependency between mods is discussed first. This area will actually pose no problem as long as TAF is aware of its existence. A new method to deal with the dependency is presented. This method may easily be incorporated into the P4 model and TAF will eliminate this potential problem. The second problem considered is the fact that the AHP does not consider uncertainty. An example is presented that compares the results obtained from using the AHP and those obtained from using DA (a method that does consider uncertainty). The end result is that TAF may want to consider uncertainty in their data by using DA to obtain some values (for example LCC savings) for the mods. These values would then be used when making the comparisons. The third problem discussed concerns the inconsistency in mod values that may be caused by using different comparison scales.

Alternative Methods. Two alternative methods are presented which may be suitable for TAF to use for their

decision problem. The first method, DA, is able to represent the uncertainty that TAF may encounter and also provides a firm foundation for the analysis. The second method, the PROMETHEE, is a method that is used to select and rank projects. The advantage of this method is that it is not overly sensitive to small changes in the comparison scale (which is a drawback of the AHP).

Further Research

The areas for further research may be divided into two main areas. First, the data used to make the pairwise comparisons requires more work to be done. Second, if TAF decides to implement either DA or the PROMETHEE method to solve their problem, more work will needed in those areas.

Data. A new tree was developed for TAF (i.e. NEWTREE) that requires data on the LCC savings. This is not a simple area to work in since LCC embodies such an extensive set of costs, for example spares, technical orders, fuel, and training. TAF needs to decide what level of detail they need and then acquire and synthesize the relevant pieces of data.

The R&M tree also poses new data requirements for TAF. The types of data that will be used to evaluate each goal, as well as the sources for some of this data must be decided upon. This task may be simplified by new software, such as

SCOPE and MARGI, that calculate combat capability and LCC, but the task is still quite involved.

New Methods. If TAF decides to use DA to solve their prioritization problem, they will need to do two things. First, they will need to figure out a methodology for obtaining the relevant probability distributions of the cost and benefit data. Second, they will need to figure out a methodology for assessing values of the alternatives (i.e. what weights are correct and what decision elements are needed). The difficult part will be determining a value function for the R&M improvement in terms of dollars.

If TAF decides to use the PROMETHEE method, they will need to define their preference functions for each decision element.

Bibliography

1. Belton, Valerie and Tony Gear. "On a Short-Coming of Saaty's Method of Analytic Hierarchies," Omega, 11: 228-230 (1983).

2. Blalock, Capt Stephen, Reliability/Maintainability Engineer. Personal interview. ASD/AEMOF, Wright-Patterson AFB OH, 10 September 1987.

3. Bowlin, Major William F. "Report on Evaluating the Efficiency of Real Property Maintenance Activities in the Air Training Command." AFIT/LS, Wright-Patterson AFB OH, November 1984.

4. Brans, J.P. and others. "How to Select and How to Rank Projects: The PROMETHEE Method," European Journal of Operational Research, 24: 228-238 (1986).

5. Collins, Capt Wallace, Chief of Maintenance Division of Special Management Organization for Reliability and Maintainability. Personal interview. HQ TAC/SMO-R&M, Langley AFB VA, 28 April 1987.

6. Crane, Jerry C. "Ranking Class IV Aircraft/Missile Modifications (HO40) Final Report." HQ AFLC, Wright-Patterson AFB OH, 13 June 1986.

7. Expert Choice. Decision Support Software, Inc. Mclean VA. September 1986.

8. Grant, Eugene L. and others. The Principles of Engineering Economy. New York: John Wiley & Sons, 1982.

9 Kamenetsky, Ricardo D. "The Relationship Between the Analytic Hierarchy Process and the Additive Value Function." Decision Sciences, 13: 702-713 (October 1982).

10. Matheson, James E. "Decision Analysis of Space Projects: Voyager Mars," The Principles and Applications of Decision Analysis, Volume 1, edited by Ronald A. Howard. Strategic Decisions Group, 1983.

11. -----. "An Introduction to Decision Analysis," The Principles and Applications of Decision Analysis, Volume 1, edited by Ronald A. Howard. Strategic Decisions Group, 1983.

12. "MODAS: Maintenance and Operational Data Access System." HQ AFLC/MMES, Wright-Patterson AFB OH, 1 April 1987.

13. Morris, Peter A. and Shmuel S. Oren. "Multiattribute Decision Making by Sequential Resource Allocation," Operations Research, 28: 233-252 (January-February 1980).

14. Moskowitz, Herbert and Gordon P. Wright. Operations Research Techniques for Management. Englewood Cliffs NJ: Prentice-Hall, Inc., 1979.

15. Oppenheimer, Kenneth R. "A Proxy Approach to Multi-Attribute Decision Making," Management Science, 24: 675-689 (February 1978).

16. Quade, E. S. and W. I. Boucher. Systems Analysis and Policy Planning: Applications in Defense. Santa Monica CA: The Rand Corporation, June 1968.

17. "R&M Today... Combat Capability Tomorrow." Briefing on SCOPE, MARGI. USAF/LE-RD. July 1986.

18. Russell, LTC Stephen H. "Discounting in Defense Decision Analysis." The Air Force Comptroller: 4-9 (July 1985).

19. Saaty, Thomas L. The Analytic Hierarchy Process. New York: McGraw-Hill, Inc., 1980.

20. -----. Decision Making for Leaders. Belmont CA: Lifetime Learning Publications, 1982.

21. ----- and others. "High-Level Decisions: A Lesson from the Iran Hostage Rescue Operation." Decision Sciences, 13: 185-206 (April 1982).

22. Schooff, Lt Richard M., Scientific Analyst. Personal interview. HQ TAC/XP-JSG, Langley AFB VA, June 1987.

23. Sobol, Marion G. "Book Reviews," Interfaces, 14: 97-101 (May-June 1984).

24. "Tactical Forces Multicommand Reliability and Maintainability R&M 2000 Plan." HQ TAC, Langley AFB VA, 30 December 1986.

25. Taylor, John. "Flying by the Facts," Business Computing and Communications: (April 1986).

26. Watson, S. R. and A. N. S. Freeling. "Assessing Attribute Weights," Omega, 10: 582-583 (1982).

27. Zahedi, Fatemeh. "The Analytic Hierarchy Process- A Survey of the Method and its Applications," Interfaces, 16: 96-108 (July-August 1986).

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19. (continued)

The purpose of this research was to validate TAF's decision making process that generates a prioritized list of R&M modifications and to suggest other possible approaches to solve the problem.

The first part of the research, the validation, was done in three sections. The first section demonstrated that TAF does not completely satisfy the requirements to meet a specific set of decision criteria, but the shortcomings may be easily corrected. Also explained was the applicability of using the AHP to solve TAF's problem. The second section scrutinized TAF's use of the AHP to determine problem areas. The tree structure and the data were discussed and possible fixes were introduced. The third section highlighted three shortcomings contained within the AHP. The topics of dependency between the mods, uncertainty in the data, and the scale used to make the pairwise comparisons were discussed in detail. Ideas on approaches to avoid these problems were presented.

The second part of the thesis proposed the alternative methods of decision analysis and PROMETHEE to solve TAF's prioritization problem.

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